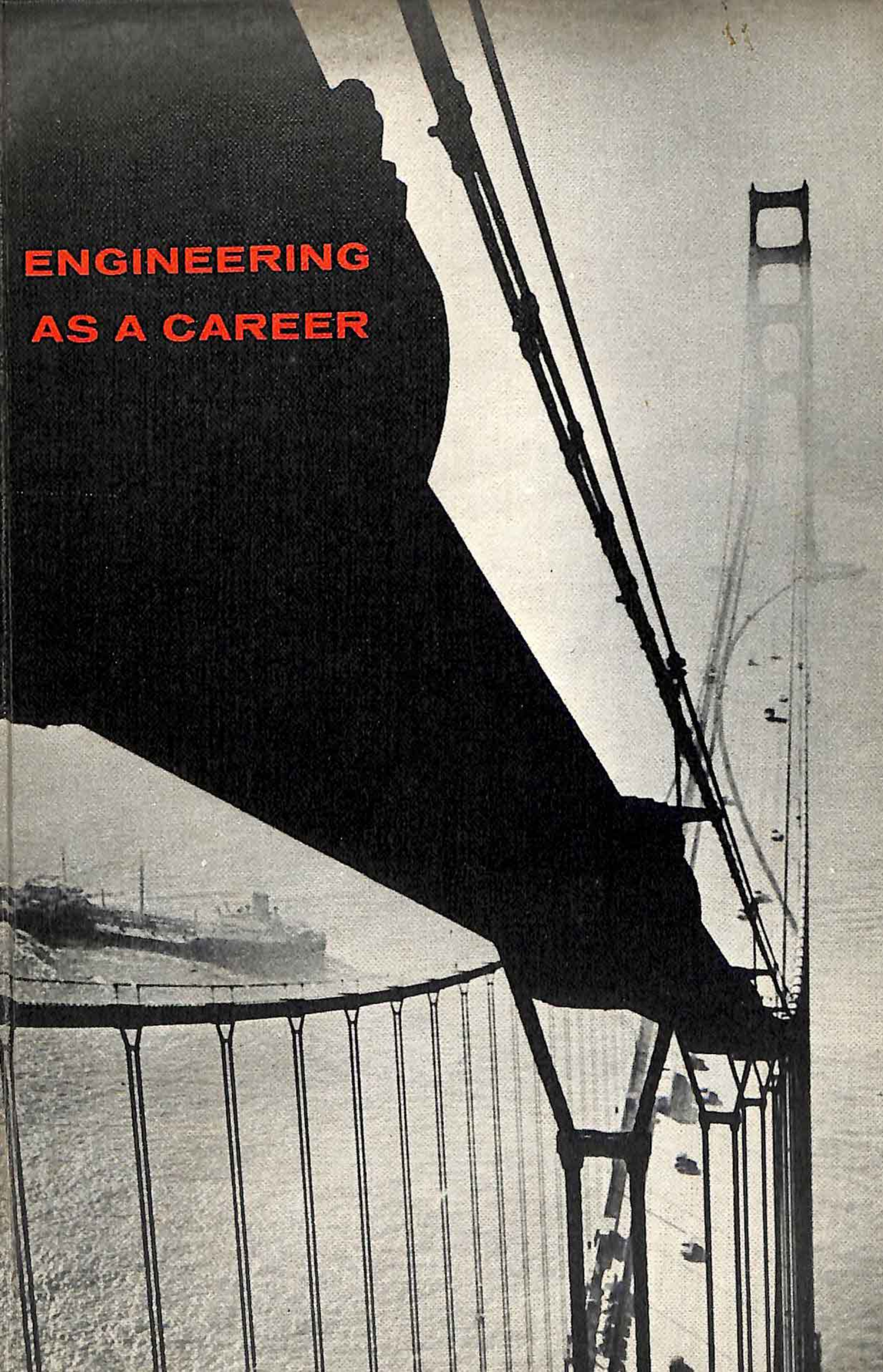
ENGINEERING AS A CAREER



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Engineering as a Career

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McGRAW-HILL BOOK COMPANY, INC.

New York · Toronto · London · 1956

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ENGINEERING AS A CAREER

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Library of Congress Catalog Card Number 56-7567

Cover photograph courtesy of Standard Oil Co. (N. J.)

THE MAPLE PRESS COMPANY, YORK, PA.

To Louise
whose every interruption
was an inspiration

PREFACE

Every engineering adviser is aware of the fact that the great majority of freshmen and a surprisingly large percentage of seniors have only a vague idea of just what engineering is. In many engineering schools a freshman orientation course has been set up to explain the nature of engineering, describe the work of professional engineers, and indicate the requirements for success in the profession. This book is an outgrowth of experience gained in teaching such a course over the past ten years.

The presentation has been designed to accomplish six major objectives:

1. *To acquaint beginning students with engineering as a career.* Career planning is of the greatest importance, and yet few students enter engineering as a result of matching their own abilities with the qualifications needed for success in this exacting field. Surveys indicate that many students begin engineering study because they have a liking for mechanical things, a friend who is an engineer, a father who wishes he had studied engineering, or a mother who notes that engineers are in demand at good salaries. We need to interest an ever-increasing number of high school graduates in careers in science and engineering, but there is a great loss in time, money, and talent by those who invest several years in engineering study only to discover that it is not what they had imagined. Proper orientation at the beginning of the freshman year should reduce this loss.

2. *To indicate the qualifications, duties, and responsibilities of engineers.* In striving to interest young people in engineering, we must avoid overselling the marginal student. One aim of this book is to present a factual picture of just what engineers do and what qualifications and training are required in the practice of engineering. Such a description should be an aid in vocational counseling and should result in an improved engineering profession.

3. *To define the engineering profession in terms of functions as well as branches.* Engineering can be classified by branch—civil, electrical, mechanical, mineral, chemical, etc.—or by function—research, development, design, construction, production, operation, application, industrial, management. In the author's opinion, a student's *interest* may lie in a certain branch, but his *aptitudes* are most closely related to a certain function. The functional classification, therefore, is much more meaningful from the standpoint of career planning. This book is unique among orientation texts in that the functional approach is emphasized.

4. *To provide motivation for the study of pre-engineering courses.* In the usual engineering school, the student spends his first two years in other departments obtaining a knowledge of fundamentals. He has little opportunity to do what he came to school for—to study engineering. Motivation is provided by mapping out a typical 4-year curriculum, indicating the relationships between beginning and advanced courses. Mathematics, English, and drawing are discussed in terms of their applications. Brief introductions to some of the engineering sciences are included to stimulate interest in the basic sciences.

5. *To provide training in the philosophy and technique of problem solution.* The activity characteristic of all engineering is problem solution. Usually the approach to complete problems is not discussed until the senior year, and, obviously, any presentation at the freshman level must be limited to the most elementary situations requiring little technical background. Including it here enables the student to view with a proper perspective the "exercises" usually treated in college courses and, more important, gives the student the feeling that he is on the way to becoming an engineer.

6. *To preview the basic engineering sciences and demonstrate their application.* While most of the book is descriptive, an attempt has been made to include some technical material which is comparable to the work of the junior year. Space and time permit only brief introductions to a few topics including materials and mechanics, steam power, internal-combustion engines and refrigeration, electric circuits, machines and electronics, and engineering economy. These were selected as representative of the three major fields of interest: civil, mechanical, and electrical engineering. In treating these topics, compromises were made so that the approaches used fit the background of beginning students. For example, the method of capital recovery by straight-line depreciation plus average interest is used because the derivation is followed easily and the method can be employed without recourse to special tables.

Designed for a two-unit course of approximately 32 class meetings, the book consists of three major parts: The Engineering Profession, College Training of the Engineer, and The Engineering Sciences. It is also suitable for three-unit courses where more emphasis is placed on problems. Where only one unit can be devoted to orientation, the treatment of engineering sciences can be minimized or omitted. The text material may be supplemented with talks by practicing engineers or motion pictures of engineering activities. Much of the material on engineering functions has come from the experiences of the nearly 50 engineers who have talked to our classes.

RALPH J. SMITH

ACKNOWLEDGMENTS

In writing an engineering book, the original contribution of the author is negligibly small. The facts, principles, methods, and viewpoints presented here are due to the work of a few eminent engineers, brilliant scientists, and industrial leaders and to the labor of a host of anonymous engineers, painstaking researchers, and humble teachers. In addition to making possible the wonders of this engineering age, these unsung workers have made available to all who desire to learn a treasure of scientific and technological knowledge. I salute them and gratefully acknowledge their contributions to this presentation.

Specific mention should be made of Edward Bennett of the University of Wisconsin who in 1923 proposed a functional classification of engineering training. This approach was brought to my attention by Dean L. M. K. Boelter of the University of California (Los Angeles), and the concept of the engineering spectrum was developed in conversations with Dean Frederick E. Terman of Stanford University. Much of the chapter on oral and written reports is based on the excellent text, "Writing the Technical Report" by J. Raleigh Nelson (McGraw-Hill Book Company, Inc., 1952). In preparing the material on problem solution I was greatly influenced by the excellent treatment of "The Engineering Method" by T. J. Hoover and J. C. L. Fish in "The Engineering Profession" (Stanford University Press, 1950).

My thanks go to my colleagues N. O. Gunderson, E. A. Dionne, C. D. Olds, G. M. Sicular, W. J. McLarney, and J. A. Bailey for their helpful criticism of portions of the manuscript; Mr. Dionne also prepared many of the line drawings. I also wish to thank Lois Bowman, Lillie Kawamura, and Betty Taylor for their skillful handling of the manuscript.

R. J. S.

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PART ONE

THE ENGINEERING PROFESSION

1

INTRODUCTION

What is engineering?

What do engineers do?

What does engineering have to offer as a lifetime vocation?

What qualifications are required for success in engineering?

This book has been written to provide answers to these and other questions in the minds of young persons considering a career in professional engineering.

The selection of a vocation is one of the most important decisions you will ever make, and it is a decision which you must make yourself. You can follow a trial-and-error process, trying one type of work after another until you are satisfied, or you can proceed systematically, attempting to match your interests and aptitudes with the opportunities and requirements of available vocations.

Career selection can be broken down into three steps. First, you should decide what you want out of life—material success or opportunity for service, security or freedom of action, opportunity for leadership or freedom from responsibility, social prestige or personal privacy, creative satisfaction or freedom from pressure. On these and many other points you should decide what will contribute most to the life you wish to lead. Second, you should decide what aptitudes and other qualifications you possess. Are you skillful in working with ideas, with tools, with mathematics, with equipment, with people, with money? Are you artistic, scientific, industrious, dextrous, creative, intelligent? What are your weaknesses?

Having determined what you are after and what qualifications you have, you should then consider a variety of occupations and see which one comes the closest to offering what you want in return for work for which you are qualified. If this book helps you to understand the nature of engineering; the opportunities for interesting work, achievement, and compensation which exist in this broad field; and the mental and personal qualifications engineers should have, then its purpose will be accomplished.

The Nature of Engineering

In many respects the story of engineering is the story of civilization itself.* Civilization has been described as the process whereby man strives to overcome the obstacles in his way and become master of his environment. Engineers are constantly at work seeking to understand the laws of the physical universe, to take advantage of the beneficial aspects of nature, and to convert or modify the adverse factors. While overcoming the material obstacles in man's path, the engineer also contributes to man's moral and spiritual welfare by removing some of the causes of want and fear.

Perhaps you were attracted to the study of engineering without knowing just what it is. In describing the engineering profession (Part One of this book), we shall first set up working definitions of *engineering* and *engineer* and later on distinguish between the engineer and his coworkers the *scientist* and the *technician*. To provide the proper perspective for studying engineering as it is practiced today, a brief history of engineering from ancient to modern times is included. It will be seen that engineering, like civilization, is a changing thing and the rate of change is ever-increasing.

The primary emphasis in this section, however, is on what engineers do and how they do it. The broad field will be discussed in terms of the *branches* of civil, mechanical, electrical, mineral, and chemical engineering and the more specialized sub-branches. Of particular interest to you as a beginning student are the *functions* of engineering—research, development, design, construction, production, operation, application, industrial, and management. You will be able to compare your aptitudes with those required for success in each of the various functions.

Opportunities in Engineering

Engineering is one of the largest of all professions, with over 600,000 members in the United States. Although it is the youngest of the organized professions, its record of achievement is already impressive. Public recognition of the contributions made by engineers has brought new opportunities for service and, at the same time, an even greater need for high standards of personal and professional conduct (see Chap. 4).

How much will you earn as an engineer? Engineering salaries are dependent upon individual qualifications, experience, and education and, to a lesser extent, upon industry, type of employer, branch of engineering, and geographical area. In Chap. 8 the results of various studies and salary surveys are presented in graphical form to indicate the effect of the various factors. The opportunity for material rewards for engineering work appears to be quite good.

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* James K. Finch, "Engineering and Western Civilization," McGraw-Hill Book Company, Inc., New York, 1951.

Of greater importance, however, is the sense of accomplishment which comes with creative and constructive work. Engineers are builders and inventors and designers and operators and managers. As an engineer you will play an important role in the development of our technological society. To make the maximum contribution, you will need to understand how our society operates and how individuals behave; in this connection the necessity for training in the humanities as well as in the sciences will be discussed.

Qualifications for Success in Engineering

Are you suited for work in engineering? Engineering is not a single activity; rather it is a broad spectrum of activities or functions. While all functions of engineering have some common characteristics, there is a wide variation in emphasis, and certain abilities are of much greater importance in some engineering activities than in others. A major section of this book is devoted to a detailed discussion of desirable mental and personal qualifications to help you decide if engineering is the career for you and where in engineering you would fit best.

To develop your aptitudes and prepare you for entrance into the engineering profession, the engineering program provides 4 or more years of concentrated training. Part Two is concerned with the college training of an engineer. To illustrate how general education and training in the basic sciences are integrated with advanced engineering work, a typical engineering curriculum will be presented and the various component courses briefly described.

This is not just a book *about* engineering, however; in some respects it is an engineering textbook similar to those you will be studying during the next 4 years or so. Technical material from the fields of civil, mechanical, and electrical engineering is included in Part Three so that you can test your ability to follow mathematical discussions, grasp scientific concepts, and solve engineering problems. Special training is provided in the engineering approach to technical problems.

A Look to the Future

America's professional engineers are finding new ways to control the forces of nature, raise our standard of living, and build our defenses; just a few years ago they were in your situation, trying to decide on a career. The technological developments of the future will come from young people who, like you, are just starting their professional training. The need for qualified persons is great, and the opportunities are unlimited; you are embarking on a lifetime of satisfaction if you decide on engineering as a career.

2

DEFINITION OF THE ENGINEERING PROFESSION

There is a great deal of confusion in the minds of the general public as to just what is engineering. In view of that confusion, let us take time now to set up some working definitions to be used throughout the course. We shall first examine definitions which have been proposed from time to time and pick out what appear to be the fundamental elements of a satisfactory definition of "engineering" and "engineer." Subsequent chapters will provide illustrations of engineering projects and detailed discussions of the work of engineers to make clear the nature of engineering.

DEFINITIONS OF "ENGINEERING"

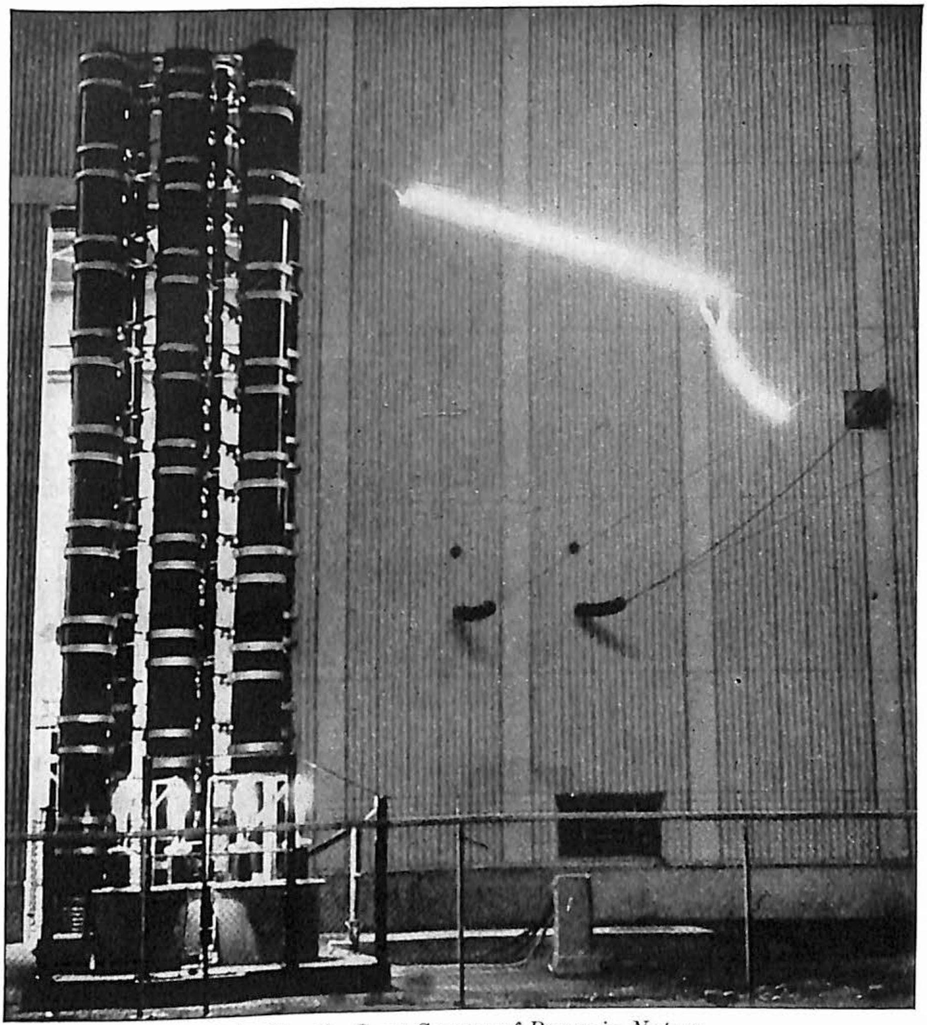
Engineering is a relatively new profession, and engineering activities are continually changing in nature and scope. Among the many attempts which have been made to define engineering, the following, listed in chronological order, are of interest. As you read them, note the varying emphasis in the statements.

Thomas Tredgold (1828): Engineering is the art of directing the great sources of power in nature for the use and convenience of man.

A. M. Wellington (1887): It would be well if engineering were less generally thought of, and even defined, as the art of constructing. In a certain important sense it is rather the art of not constructing; or, to define it rudely but not inaptly, it is the art of doing that well with one dollar which any bungler can do with two after a fashion.

Henry G. Stott (1907): Engineering is the art of organizing and directing men and controlling the forces and materials of nature for the benefit of the human race.

Willard A. Smith (1908): Engineering is the science of economy, of conserving the energy, kinetic and potential, provided and stored up by nature for the use of



Directing the Great Sources of Power in Nature

One of the basic objectives of high-voltage research is to determine the effects of lightning upon power transmission lines. The mobile impulse generator consists of a group of giant condensers which are charged in parallel at a relatively low voltage and then discharged in series to provide a high voltage. The resulting 7,500,000-volt bolt of man-made lightning is then shot at a test section of transmission line. (*General Electric Company.*)

man. It is the business of engineering to utilize this energy to the best advantage, so that there may be the least possible waste.

H. P. Gillette (1910): Engineering is the conscious application of science to the problems of economic production.

Alfred W. Kiddle (1920): Engineering is the art or science of utilizing, directing or instructing others in the utilization of the principles, forces, properties and substances of nature in the production, manufacture, construction, operation and use of things . . . or of means, methods, machines, devices and structures . . . .

S. E. Lindsay (1920): Engineering is the practice of safe and economic application of the scientific laws governing the forces and materials of nature by means of organization, design and construction, for the general benefit of mankind.

R. E. Hellmund (1929): Engineering is an activity other than purely manual and physical work which brings about the utilization of the materials and laws of nature for the good of humanity.

J. A. L. Waddell, Frank W. Skinner, and H. E. Wessman (1933): Engineering is the science and art of efficient dealing with materials and forces . . . it involves the most economic design and execution . . . assuring, when properly performed, the most advantageous combination of accuracy, safety, durability, speed, simplicity, efficiency, and economy possible for the conditions of design and service.

T. J. Hoover and J. C. L. Fish (1941): Engineering is the professional and systematic application of science to the efficient utilization of natural resources to produce wealth.

DEFINITIONS OF "ENGINEER"

In addition to the foregoing definitions of "engineering," there are two significant definitions of "engineer." The first is important because of its recognition as law. As a basis for professional registration, each state must provide a legal definition of "engineer" and the "practice of engineering." A typical provision* is as follows:

> "Professional engineer," within the meaning and intent of this act, refers to a person engaged in professional practice of rendering service or creative work requiring education, training and experience in engineering sciences and the application of special knowledge of the mathematical, physical and engineering sciences in such professional or creative work as consultation, investigation, evaluation, planning or design of public or private utilities, structures, machines, processes, circuits, buildings, equipment or projects, and supervision of construction for the purpose of securing compliance with specifications and design for any such work.

The second definition is significant because it has been approved by representatives of a large segment of the engineering profession. Accepted by delegates to a conference of engineering societies of the United States and Western Europe is the following:

> A professional engineer is competent by virtue of his fundamental education and training to apply the scientific method and outlook to the solution of problems and to assume personal responsibility for the development and application of engineering science and techniques especially in research, designing, manufacturing, superintending and managing.

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* The Civil and Professional Engineers Act of the State of California, Art. 1, Chap. 7, Division 3 of the Business and Professions Code.

ELEMENTS COMMON TO THE VARIOUS DEFINITIONS

As we study the foregoing definitions, certain key words and phrases appear over and over again—"art," "science," "application of science," "organizing and directing," "sources of power," "natural resources," "safety," "economy," "efficiency," "professional," "scientific method," "benefit of the human race," "good of humanity." A careful consideration of these definitions and engineering as it is practiced today leads to the conclusion that there are six essential elements in defining engineering:

Engineering is a profession.
Engineering is an art rather than a science.
Engineering is based on the application of science.
Engineering is concerned with efficiency, economy, and safety.
Engineering involves the utilization of natural resources.
Engineering has as its ultimate purpose the benefit of man.

Incorporating these six elements into a single statement results in the following:

Engineering is the professional art of applying science to the efficient conversion of natural resources to the benefit of man.

INTERPRETATION OF THE DEFINITION

This definition has the virtue of brevity, but its use requires a thorough understanding of the key phrases. Let us consider the six essential elements one at a time.

Professional

What is a profession? The vocations commonly referred to as professions include law, medicine, ministry, teaching, architecture, and engineering. In general these have three common characteristics: Associated with each profession is a great body of special knowledge; preparation for the profession includes training in applying that knowledge; in practicing the profession, each member must recognize his responsibilities to the public over and above his responsibilities to his client and to other members of the profession. Certainly engineering qualifies as a profession on all three counts.

Art

An art is based on a set of principles and rules for doing a certain work well. It includes the systematic application of knowledge and/or skill. Engineering involves the practice of skill and ingenuity in adapting knowledge to practical purposes. Judgment based on experience is necessary.

The major part of engineering work consists of solving problems. The "engineering method" or "scientific method" of problem solution involves a clear statement of the problem and assumptions, a scientific analysis of the facts, a careful checking of the results, drawing conclusions from the facts, and sticking to those facts.

Applying Science

Science is accumulated, established, and systematized knowledge. Engineering is based on the fundamental sciences of physics, chemistry, and mathematics and their extension into thermodynamics, electrodynamics, metallurgy, and mechanics of solids and fluids. The word science is derived from the Latin *scire*, which means "to know." In contrast, the function of the engineer is "to do." The scientist is concerned with adding to our store of knowledge. The engineer brings science to bear on practical problems; he is a man of action.

Efficient Conversion

The raw materials with which engineers work seldom are found in useful forms. Engineering of the highest type is required to imagine, design, and accomplish the conversion of the energy of a turbulent mountain stream into the powerful torque of an electric motor a hundred miles away. Similarly there are many engineering operations between the sands of the seashore and the precise lenses which permit us to observe the microscopic amoeba in a drop of water and study the giant nebula in outer space. In a certain sense, the successful engineer is a malcontent, always trying to change things for the better.

To the engineer efficiency means output divided by input. His job is to secure a maximum output for a given input or to secure a given output with a minimum input. The ratio may be expressed in terms of energy, materials, money, time, or men. Most commonly the denominator is money; in fact, most engineering problems are answered ultimately in dollars and cents. Efficient conversion is accomplished by using efficient methods, devices, and personnel organizations.

The emphasis on efficiency leads to the large, complex operations which are characteristic of engineering. The processing of the new antibiotics and vaccines in the test-tube stage belongs in the field of biochemistry, but when great quantities must be produced at low cost, it becomes an engineering problem. It is the desire for efficiency and economy that differentiates ceramic engineering from the work of the potter, textile engineering from weaving, and agricultural engineering from farming.

Since output equals input minus losses, the engineer must keep losses and waste at a minimum. One way is to develop uses for products which otherwise would be waste. The work of the chemical engineer in utilizing

The Conversion of Natural Resources

Henry Bessemer (1813–1898) was an ingenious inventor who made many contributions to the manufacturing of paints, oils, and sugar. His need for a stronger gun metal to handle the improved projectiles he had invented led to the discovery of the Bessemer process for removing carbon and other impurities from molten iron. In the Bessemer Converter, a blast of air is forced through the crucible of molten pig iron to oxidize the impurities—silicon, manganese and carbon—leaving a low-carbon, "mild" steel with greatly improved physical properties. (*A. M. Byers Company.*)

successively greater fractions of raw materials such as crude oil is well known. Friction losses occur in every machine and also in every organization. Efficient functioning depends on good design, careful attention to operating difficulties, and lubrication of rough spots, whether they be mechanical or personal.

Natural Resources

In general there are two types of natural resources—materials and energies. These are the elements from which engineers have fashioned their works.

Conserving the Energy Provided by Nature for the Use of Man

Here is a new application of the vast energy of the sun—ultimate source of most of the energy available to man. This solar-powered unit uses wafer-thin disks of silicon connected together to form a 432-cell battery. Silicon disks are extremely sensitive to light and can deliver power at the rate of 100 watts per square yard of effective surface. The device has no moving parts or corrosive chemicals and will furnish power even in poor light. It is being used here to energize a rural telephone line. (*Bell Telephone Laboratories.*)

Engineering materials include animal, vegetable, and mineral items—some natural and some produced. Materials are useful because of their properties: their strength, ease of fabrication, lightness, or durability, their ability to insulate or conduct, their thermal, electrical, or acoustical characteristics. A list of these materials would be almost limitless; for example, there are 45 metallic elements and nearly 8,000 alloys of those metals in commercial use today.

The number of important sources of energy is much smaller—coal, petroleum, gas, wind, falling water, the sun's rays, nuclear fission. Each energy form has characteristics which dictate its use in certain situations. Coal is cheap. Petroleum products can be converted into heat under carefully controlled conditions. Wind power is cheap but undependable. Development of water power is feasible only in certain, usually remote, areas. Electrical energy is obtained indirectly from some natural form and therefore is expensive, and it cannot be stored; however, it possesses the great advantages of efficient transmission, distribution, and utilization in a great variety of applications.

At the present time we are not making direct use of the tremendous amounts of energy which are received from the sun. Each day there comes to the earth as sunshine more than 20,000 times as much energy as mankind uses for all purposes. The use of nuclear energy on a commercial scale is imminent. A 60,000-kw unit to serve a city of approximately 100,000 population will consume about 15 lb of fuel per month in contrast to the 40,000,000 lb of coal per month required by a typical steam-generating plant.

Some natural resources are renewable; others are used up. The engineer must concern himself with conservation, which means more than just "not using." True conservation requires continual development of new resources as well as efficient utilization of present resources. Some authorities have expressed concern over the rapid depletion of such resources as petroleum and high-grade iron ore. The history of civilization seems to indicate, however, that long before our present resources are exhausted, engineers and scientists will have uncovered new sources, developed improved methods of processing, and discovered better replacements.

Benefit of Man

Is the atomic bomb of benefit to man? This far-reaching question may not be answered until World War II and the subsequent international tension are matters of history. It is obvious that many of the contributions of the engineer have political and social implications far beyond the immediate technical results. Sometimes the benefit realized may be questionable, as in the case of the Great Pyramid; other engineering achievements, such as an intercontinental missile of war, may benefit one segment of society while threatening another.

In general, however, the results of engineering activities contribute directly to the welfare of man. A complete list would include items which furnish food, shelter, comfort, and convenience and which make work, transportation, communication, and recreation easier and safer. The various Registration Acts justify the legal recognition of the engineering profession "in order to safeguard life, health, property and public welfare." Certainly all engineering work must meet the test: Will it be of benefit to man?

DEFINITION OF ENGINEER

Having developed a working definition of "engineering," we have a basis for prescribing what constitutes an engineer.

An engineer is qualified by aptitude, training, and experience to perform engineering functions.

Let us discuss further the key phrases in this definition.

Aptitude

Aptitude implies a disposition toward or a capacity for work in a certain field. One characteristic of engineering study is that a certain type of mind is desirable. The purpose of engineering education is to draw out, develop, and train inherent abilities or aptitudes.

It is, of course, not possible to say with certainty whether or not a particular individual should enter the engineering profession; however, certain traits are closely correlated with success in engineering. These include interest in and aptitude for the basic sciences of mathematics, physics, and chemistry; skill in applying science to practical problems; ability to visualize physical relations described in words; aptitude for translating verbal statements into mathematical terms and for interpreting mathematical results in terms of practical objectives.

Engineering is essentially a mental activity. While the engineer is concerned with machines, structures, and other concrete objects, his responsibility is the solution of abstract problems involving design, performance, efficiency, and cost. Sometimes a liking for taking clocks apart or building model airplanes is presumed to be positive evidence of aptitude for engineering. But skill in manipulating tools and machines is more important to the technician than to the engineer, although practical knowledge of the physical characteristics of technical devices is valuable as background for engineering study.

Training

The development of engineering training has kept pace with the progress of engineering knowledge. The present engineering school is a good solution to the problem of preparing young engineers in a short time for a great variety of beginning positions.

The early engineers had little or no formal training. The body of recorded technical knowledge was limited, and it was common practice for a young man to serve an apprenticeship under an engineer of some reputation. Information picked up on the job was supplemented by self-education and occasional opportunities for formal schooling.

As the results of experience and research replaced trial-and-error methods, the established engineering principles became so numerous that no one individual could provide the necessary training. A course of systematic instruction in an organized engineering school became the accepted road to professional practice. A recent survey (1950) indicated that nearly 81 per cent of the engineers then practicing had completed a college program. In 1930 the figure was only 73 per cent.

Laboratory Training in Elementary Metallurgy

The engineering program provides an effective combination of scientific, technical and practical training. Here a group of sophomore students is becoming familiar with the effect of heat treating on physical properties. The cylindrical specimen is heated to a specified temperature in the furnaces and quenched under controlled conditions in the water bath. (*San Jose State College Photo.*)

The engineering faculty represents a corps of specialists in their various fields. The college faculty, laboratories, and libraries provide opportunities for learning which are not to be found in any other situation. The 4-year engineering program is designed to provide a concentrated, efficient, stimulating, and even pleasant period of education.

Experience

Engineers are not completely trained in college; graduation is not the end of training. For efficiency the college program must be quite general, emphasizing fundamental principles and omitting the specialized knowledge needed on a given job. In most states the college graduate is permitted to take, as a first step toward professional registration, an examination covering engineering principles and application techniques. Those successful in the examination are certified as Engineers-in-Training (E.I.T.).

Actual engineering, however, is an art which requires practice in its development. Experience is needed to develop judgment as a basis for decisions. The important engineering problems cannot be reduced to simple formulas, nor can answers be found in charts and tables. Engineers are valuable when they are able to make sound decisions based on scientific principles in combination with practical experience. The second step leading to professional registration includes an examination designed to test that ability.

Engineering Functions

While the general field of engineering has been defined, it is important to realize that engineering is not a single activity. Rather it is a wide range of activities. At one extreme it borders on the work of the "pure" scientist—the physicist, the chemist, the mathematician. At the other extreme the engineer rubs shoulders with the technician—the draftsman, the surveyor, the stress analyst. The engineering spectrum includes the research engineer working at the frontier of knowledge as well as the maintenance engineer planning and supervising the repair of plant equipment.

The classification of engineering into *branches* of chemical, civil, electrical, mechanical, mining, and petroleum engineering is in terms of what the engineer works *with*. From the standpoint of the student a much more meaningful subdivision is by *function*, which is related to what the engineer *does*. The major engineering functions are

Research
Development
Design
Construction
Production
Operation and Maintenance
Application and Sales
Industrial
Management

Because this classification is of such great importance to the student contemplating a career in engineering, these functions will be discussed in detail in Chap. 6.

SUMMARY

The engineering profession can be described and defined in terms of two brief definitions:

Engineering is the professional art of applying science to the efficient conversion of natural resources to the benefit of man.

An engineer is qualified by aptitude, training, and experience to perform engineering functions.

These statements provide the basis for a more detailed study of engineering as a career.

ASSIGNMENTS

2-1. In order to get first-hand information about engineering, interview an engineer and obtain the following data: name, employer or place of business, title of position held, qualifications required, duties and responsibilities, other pertinent information. This will occupy approximately one-half page.

On the other half-page, discuss this engineer's job in terms of the definitions presented in this chapter. In your discussion answer the questions "Is he an engineer?" and "Is he practicing engineering?"

If there are no engineers among your acquaintances or those of your friends, you will find that engineers employed in local industries or city, county, or state offices will be willing to help you.

2-2. Obtain from the library a biographical sketch of an American engineer. Select one period of his life, and list the title of the position he held, the qualifications required, and the duties and responsibilities. Discuss this engineer's work in terms of the definitions presented in this chapter, answering the questions "Was he an engineer?" and "Was he practicing engineering?"

2-3. Select a specific project from any one of the following branches of engineering: aeronautical, chemical, civil, electrical, electronic, industrial, mechanical, metallurgical, mining, petroleum. Describe the project in one paragraph and then determine whether it is engineering as defined here by discussing it in terms of the six elements of the definition.

2-4. The definitions listed chronologically cover a period of approximately 130 years. Write a one-page report pointing out how some of the elements of a definition of a certain period reflect developments of importance at that time. Or show how changes in the emphasis of some of the definitions correspond to changes in our economic and social structure.

3

A BRIEF HISTORY OF ENGINEERING

Having defined "engineering" and "engineer," let us now look at the background of engineering in terms of early engineers and their accomplishments. A brief review of what has gone before will enable us to understand better the relationships among the various branches of the broad profession of engineering. A detailed description of these fields of specialization as they exist today will be given in the next chapter.

ENGINEERING AND CIVILIZATION

It has been said that the history of civilization is the history of engineering. Certainly it is true that the highly developed civilizations have all been noted for their accomplishments in what we call engineering.

Modern Civilization

From the moment you are awakened by an almost magic electric alarm clock until you fall asleep in a bed the like of which no Caesar or Pharaoh possessed, you are literally surrounded by the results of engineering. You are clothed in fabrics which were unknown a generation ago, you eat foods of a fantastic variety and superlative quality, you are carried at flying speeds by the equivalent of 200 horses, and with a flick of a switch you command the talents of the most famous entertainers.

In many respects engineering achievements have paved the way for the advancement of human societies. Can you imagine life in a typical American city if, overnight, all the contributions of the engineer were removed? One of the most terrifying aspects of atomic warfare is that a successful attack on an integrated community would destroy the effectiveness of most of the aids to living which we accept as commonplace. In the event of an atomic bomb attack on your city what would happen to food supply, water supply, sanitary facilities, fuel supply, transportation, and communication?

Prehistoric Developments

Prehistoric man over a period of several thousand years adapted to his own use many things which occurred in nature. *Fire* gave him warmth, protection from nocturnal beasts, means for cooking food and for signaling. The *beam,* adapted from a fallen tree, permitted him to build his "cave" in the most desirable place and to cross turbulent streams. From vines and strips of hide he made the *ropes* which are essential in so many human activities. His first *tools* were probably the knife, the axe, and the needle, all patterned after natural objects. The use of the *lever* required a high type of intelligence and resulted in a multiplication of human force even as the spear extended his reach. The first man to use the *roller* was probably the genius of the tribe; in fact his contribution to the problem of transport would have merited promotion to chief. It is interesting to note that when a modern engineer has to move a heavy machine in cramped quarters, he goes right back to his prehistoric counterpart and employs the simple lever and multiple roller.

ANCIENT ENGINEERING FEATS

The ancient peoples had mastered the construction of what we call public works: masonry structures, bridges, highways, canals, tunnels, irrigation and drainage systems, water supplies, docks, and harbors.* Some of these accomplishments are known only from written accounts and recorded legends. Other works, constructed of stone and other durable materials, still exist as monuments to their builders.

Architecture

The word "architect" means "chief builder." The early architect had to be able to plan a structure, be skilled in the art ("technology") of building, have a knowledge of materials, and be able to direct men—in other words, he was an engineer. The Great Pyramid in Egypt (3000 B.C.), King Solomon's Temple in Jerusalem (1000 B.C.), the Parthenon in Greece (450 B.C.), and the Colosseum in Rome (A.D. 80) are well-known structures which attest to the imagination and skill of their planners and builders.

Hydraulics

Water is always intimately connected with human life. The irrigation dams and canals which made the valley of the Nile a garden spot (2000

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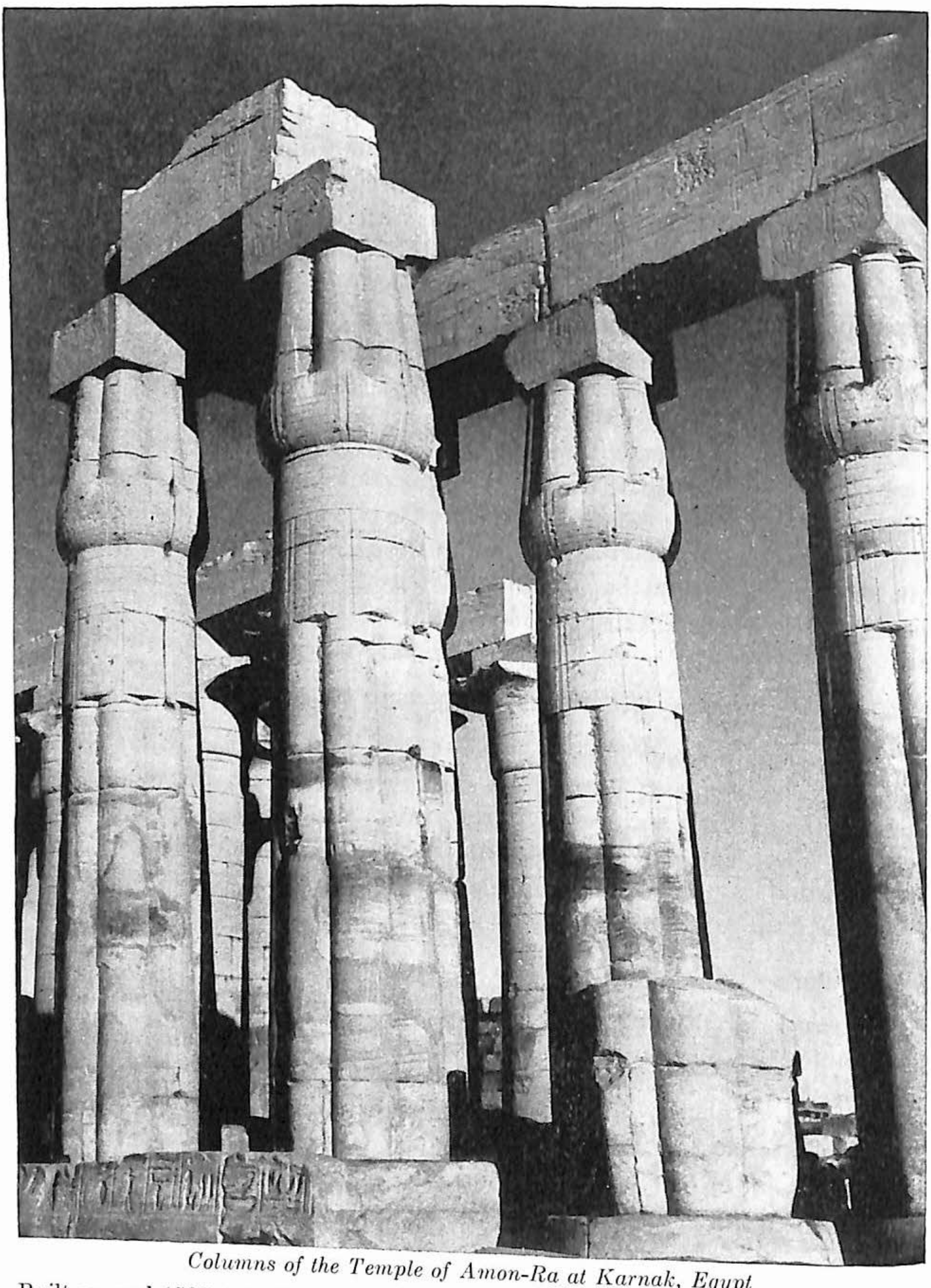
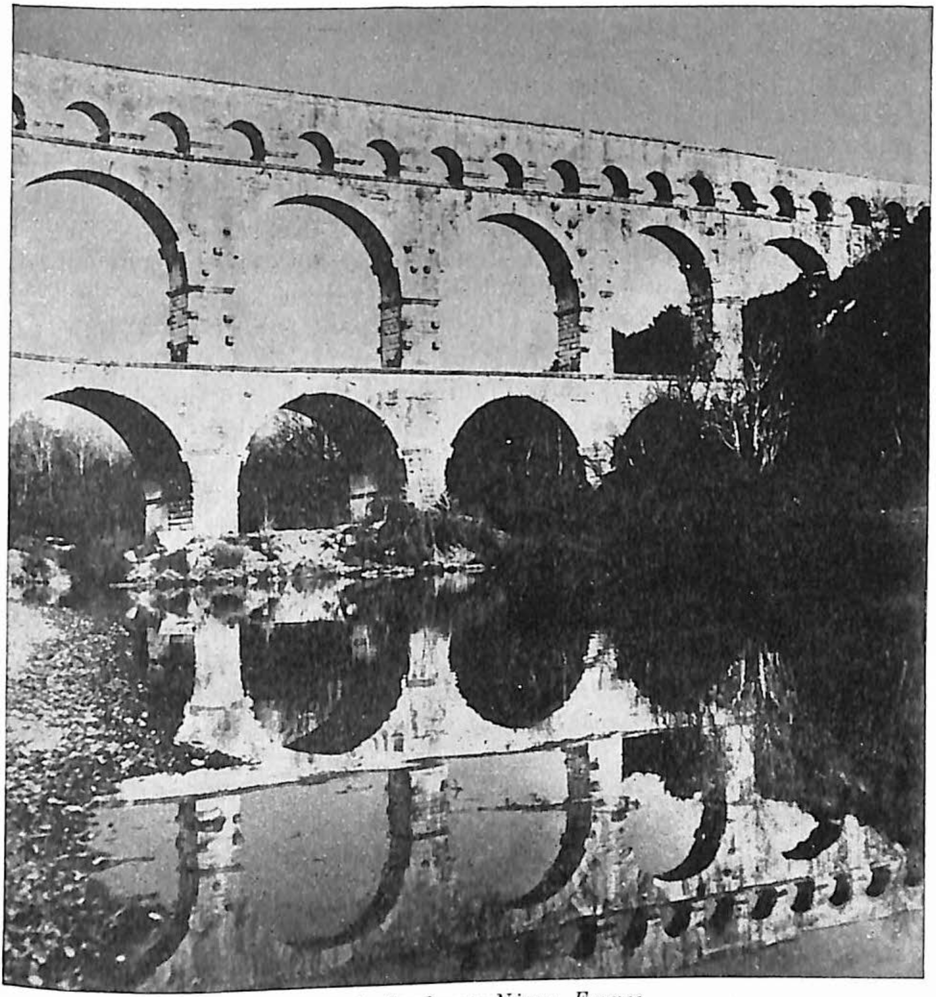
* A. P. Fleming, and H. J. Brocklehurst, "A History of Engineering," A. & C. Black, Ltd., London, 1925.



Columns of the Temple of Amon-Ra at Karnak, Egypt

Built around 1500 B.C., this was probably the largest columnar structure in the world. The quarrying, transporting, and erecting of the tremendous stone elements involved many difficult engineering problems. If the limestone columns are about eight feet in diameter at the base, what are the approximate dimensions and weight of the crossbeams on top? Lacking the screw and the pulley, how would you contrive to place the crossbeams? (*Egyptian State Tourist Administration.*)



Pont du Gard near Nimes, France

This aqueduct, built by the Romans in 19 B.C., still stands as a monument to Roman engineering. Constructed of squared stones placed without mortar, it is nearly 160 feet above the Gard River and 880 feet long. While pozzuolana or natural cement was known at that time, the necessity for elaborate forms for concrete work made stone masonry more practical. Note the triple tier of stone arches first used by the Romans. (*French Government Tourist Office.*)

B.C.) are among the earliest engineering achievements. Both Jerusalem and Athens were supplied with water from the distant hills by means of aqueducts. The Romans are famous for their 250 miles of aqueducts which were described in detail (A.D. 79) by Frontinius, a Roman surveyor and "water commissioner." It has been estimated that these aqueducts, remains of which are still standing, delivered into Rome over 300,000,000 gal of water per day.

Highways

The Romans carried their engineering into the many countries they conquered. Of interest are the remains of Roman roads found in England, some still in service as foundations for later surfaces. In the Roman Empire there were at one time nearly 50,000 miles of improved roads constructed according to principles of paving and drainage which are still followed. The administration of such a far-flung enterprise depended upon good transportation and communication.

Metallurgy

Man's use of fire in his daily life undoubtedly led to the chance discovery of the possibilities of metallurgy. You can imagine his interest in the strange flexible sheet of metal which he found after using low-melting-point copper ore in building his fireplace. Bronze was discovered early because copper- and tin-bearing ores are frequently found together. Bronze saws and drills were used in the construction of the Pyramids, and reference to workers in brass and iron is made in the Book of Genesis. Iron, with its higher melting point, was harder to work. Rare iron ore was converted with charcoal to wrought iron and then fashioned hot by the blacksmith. Its strength and rarity made iron valuable, and when not used in a prized tool or weapon, it was formed into bars which were used as currency.

MILITARY AND CIVIL ENGINEERS

Under Napoleon the French improved and extended their highway system and organized a highway administration. These roads were used primarily for military purposes, and the term "military engineer" was used to designate the man who designed and built roads, bridges, and forts.

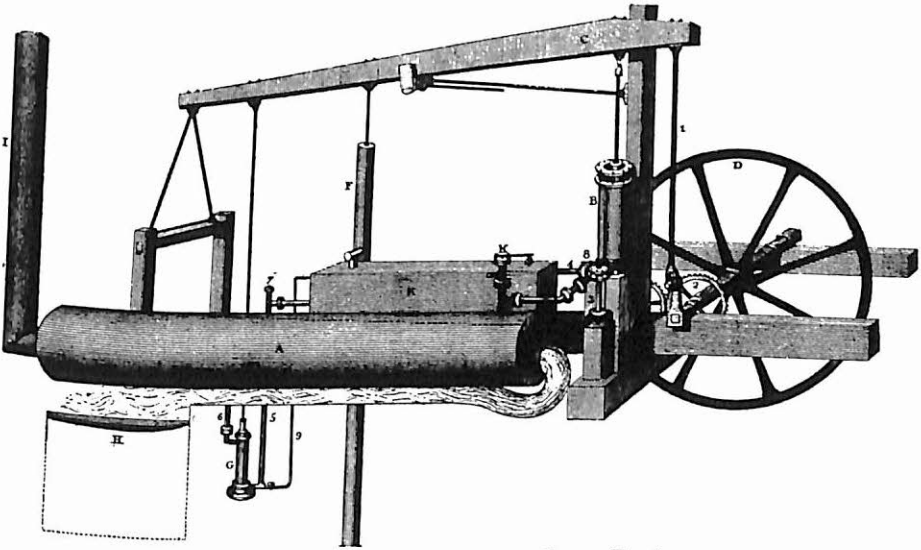
The words "engine" and "ingenious" are derived from the same Latin root *in genere*, meaning "to create." The early English verb "engine" meant to contrive or to devise. Thus the "engines of war" were clever devices such as catapults, floating bridges, and assault towers, and the designer was called the "engine-er" or military engineer. His counterpart was the "civil engineer," concerned with applications of the same knowledge and skill to devising structures, streets, water-supply and sewage systems, and other projects of benefit to the civilian population.

Civil Engineering

As was indicated previously, the ancient builders had successfully constructed most of these stationary public works. Civil engineering progress consisted in improving materials, increasing knowledge of the behavior of materials under load, and consequently in designing more efficiently. In addition progress was being made in developing sources of power. Early man depended on his own muscles for power until he domesticated the camel, the ox, and the horse. Water wheels and windmills had been used over a long period of time but only to a slight extent. Even as late as 1850 only 6 per cent of America's industrial power was furnished by machines; 79 per cent was supplied by animals, and the remaining 15 per cent was by human muscles. Today about 85 per cent of our power is supplied by machines.

THE MACHINE REPLACES MUSCLES

The end of the eighteenth century and the beginning of the nineteenth saw a great transformation in the economic life of England which has been called the Industrial Revolution. Prior to that time the economy was primarily agricultural, transportation was poor, and manufacturing was carried on in the laborers' homes. The invention of the spinning jenny (1763), the water-powered spinning machine (1771), and other mechanical devices gave rise to the factory system and created a need for mechanical



Oliver Evans's High-pressure Steam Engine

To permit a pressure of 50 psi, Evans encased the copper boiler (A) in wood bound with iron hoops. The cylinder (B) had a bore of 6 inches and a stroke of 18 inches. The piston rod worked directly on the beam (C) which was supported by a rocking fulcrum at one end and connected to the crank arm at the other. The wooden flywheel, 7½ feet in diameter, turned at 30 rpm. This American design was called the "grasshopper" and was highly successful. *(From* Nile's Weekly Register, *1813, quoted by Richard S. Kirby et al., in "Engineering in History," McGraw Hill Book Company, Inc., New York, 1956, p. 173.)*

power. The application of Watt's steam engine (invented in 1769) to the cotton, coal-mining, and iron industries greatly increased their outputs and placed England at the front in manufacturing and commerce. In the United States the corresponding transformation did not take place until after 1850.

Mechanical Engineering

Those civil engineers concerned with machines were called mechanical engineers, and as new sciences and skills developed, they became specialists in the new art. The key development was the invention of the steam engine, which made available large quantities of cheap and dependable power. (The Centennial Exposition in Philadelphia in 1876 featured a 1,000-hp Corliss steam engine.) This stimulated the development of labor-saving devices of all kinds. These in turn required more and better materials, more precise machine tools, more efficient use of fuels, more emphasis on factory planning, etc., and thus mechanical engineering was established.

ENERGY FROM THE SKY

One of nature's most awesome displays of uncontrolled energy is the lightning stroke. Under the proper conditions winds cause a separation of electric charge which builds up and up until, overcoming all restraint, the charges are equalized with a tremendous evolution of energy in the form of heat, light, sound, and, occasionally, destructive force. The opportunity for conversion of this energy to the benefit of man has always been attractive. While the engineer has not yet been able to harness this wild energy, he has been able to duplicate under controllable conditions all its desirable properties.

Electrical Science

The fact that amber (*electra* in Greek) when rubbed will attract light objects has been known for over 2,000 years. The properties of the lodestone or magnet have been known and utilized for over 1,000 years. It was not until the eighteenth century, however, that progress was made in the understanding and use of electrical energy. Benjamin Franklin's famous kite-flying experiment (1752) established the similarity between lightning and static electricity obtained from rubbing "electric" materials.

In the next 50 years European scientists laid the foundation of electrical science with their systematic observations of static electricity. The voltaic cell (Volta, 1800) made available a steady flow of current, and by 1831, Oersted, Ampère, Ohm, Faraday and other brilliant researchers had established the following facts: A flow of electric current produces a magnetic field, a moving magnetic field induces an electric voltage in nearby conductors, and the current flowing in a conductor is proportional to the voltage.

Electrical Power

The first practical application of electrical energy was in communication—the telegraph credited to Samuel F. B. Morse (1840). The telegraph was operated from bulky batteries of relatively weak voltaic cells. The Gramme dynamo (1872), which converted mechanical energy into electrical energy, was the real forerunner of the great electrical power industry. It was quickly applied to lighting, and in 1879 the first central power station was installed in San Francisco to supply Brush arc lights. These lightninglike devices had limited application, however, and it was Edison's carbon-filament lamp, patented in 1880, which provided the great stimulus for developments in generation, transmission, distribution, and utilization of electrical energy.

The new field attracted mechanical engineers familiar with rotating machinery as well as electrical experimenters. The rapid progress in the art and science of application of electricity produced a new specialist—the electrical engineer.

OUT OF THE TEST TUBE

The chemist has always been a partner of the engineer. His knowledge of the composition of substances, their properties, and methods of producing desirable changes in those properties has been an invaluable aid in engineering. His contributions are obvious in the development of metals, fuels, foods, protective coatings, and the host of other materials employed by engineers. His work was an important part of the Industrial Revolution, and the term "industrial chemist" was applied to this background associate.

Chemical Engineering

By 1880, however, the use of chemicals in manufacturing and processing had created the new chemical industry in which the production and processing of chemicals by the ton and thousands of tons was the primary concern. The design and operation of these plants were carried out by industrial chemists who had learned some engineering or by mechanical engineers who knew some chemistry. The first training program in "chemical engineering" was established in 1888 (Massachusetts Institute of Technology).

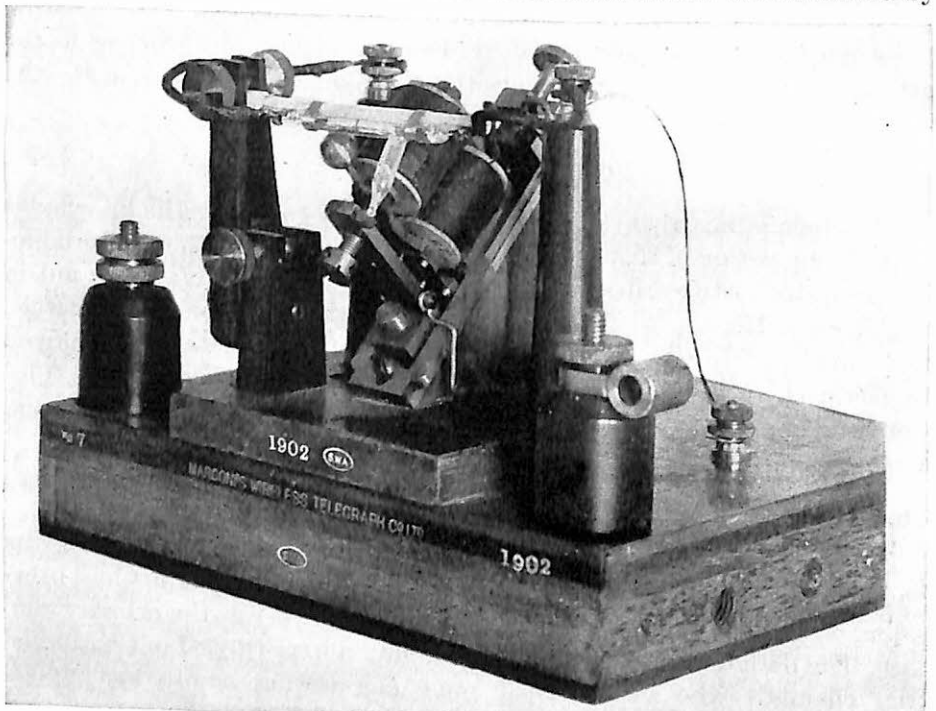
At the turn of the century the German scientists were leading the world with their discoveries in the chemistry of explosives, dyes, fuels, and synthetic materials. At the beginning of World War I, American industry found itself unprepared to supply the chemicals needed by the armed forces and by the industries manufacturing ordnance materials. The threat resulted in an unbelievably rapid expansion of the American chemical industry and firmly established the importance of the chemical engineer.

ELECTRONS IN A VACUUM

At the same time (1875) that Alexander Graham Bell and his assistant Thomas A. Watson were working on the telephone in Boston, James Clerk Maxwell of Cambridge University announced and demonstrated theoretically that electromagnetic waves travel through space with the speed of light.

Electromagnetic Radiation

Maxwell's equations are noteworthy for two reasons. In the first place they were based on no experimental evidence but rather were deduced by



1902 *Model Marconi Receiver Showing Coherer with Decohering Device*

Marconi's receiving instrument was based on the known effect of lightning flashes on collections of metal filings. The filings were found to bind together or "cohere" when subjected to electric impulses. When they did so a circuit was established through which a local current could be passed until interrupted by mechanical vibration of the filings. A tapping device caused the filings to decohere at the end of each impulse. By this means signals sent by the transmitter were registered in the same form by the receiver.

analogy from the laws of light waves. Second, nearly a century later the application of these equations in practical problems is increasing, and their study has recently been made a part of the standard training of electrical engineers.

The German physicist Heinrich Hertz corroborated Maxwell's theory in 1888 when he discovered that if he placed near an oscillating circuit a nearly closed loop of wire, sparking occurred across the gap. In 1895 Guglielmo Marconi connected a Hertz oscillator between earth and an elevated wire called an aerial and was able to detect waves at a distance of over a mile. By 1901 he had successfully transmitted signals across the Atlantic Ocean, and radio telegraphy was launched.

The Vacuum Tube

In 1883 Edison had noted a curious fact: A small current of electricity would flow between the incandescent filament and another, insulated, electrode placed within the evacuated bulb. It was not until the "electron" had been discovered that the "Edison effect" received any attention. Shortly thereafter the Fleming "valve" was used as a sensitive detector of radio waves. The introduction of a third electrode, the control grid, into the vacuum tube is credited to Lee De Forest (1906). The hot *filament* became a source of electrons which were attracted to the positively charged *plate* with the flow controlled by the *grid*. The three-electrode tube could produce, detect, or amplify radio waves or audio signals and was the basis for the rapid development of the communications field as a specialization of electrical engineering.

Electronics

At first electronics was the branch of communications which was concerned with the internal behavior of electron tubes. Now, however, communications is just one of the areas of application of electronics, which also includes industrial control, power conversion, computer operation, and the utilization of energy at frequencies from zero to a million million cycles per second and power levels from a millionth of a millionth of a watt to thousands of kilowatts.

INSIDE THE NUCLEUS

"Sixteen hours ago an American airplane dropped one bomb on Hiroshima, an important Japanese Army base. That bomb had more power than 20,000 tons of TNT . . . . It is an atomic bomb." Back of that simple statement by President Truman on Aug. 6, 1945, are some amazing examples of man's ability to reason and to learn more about his environment.

The Sun as a Source of Energy

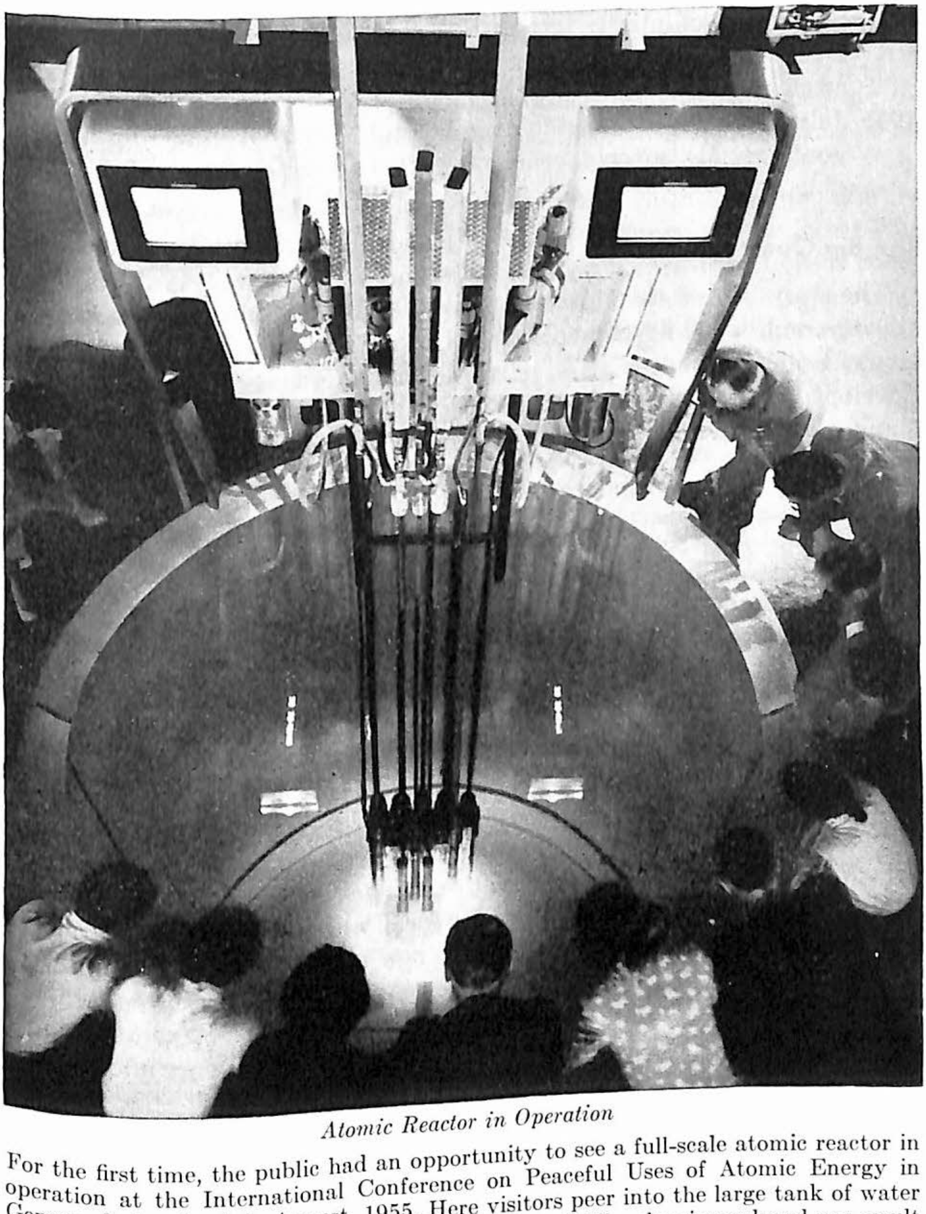
For millions of years the sun has been warming the earth's crust and making possible the life upon it; it has been the primary source of all energy on the earth. The tremendous output of the sun cannot possibly be due to the cooling of a hot body. Only recently have scientists been able to explain the mystery of its power.

In 1905, at the age of 26, Albert Einstein proposed his theory of relativity which leads to the conclusion that $E = mc^2$, or mass (m) and energy (E) are interchangeable and are related by the square of the velocity of light. Twenty-seven years later, British physicists Cockcroft and Walton demonstrated the accuracy of Einstein's theory by bombarding a lithium target with high-energy hydrogen ions and measuring the resultant energy and mass. A minute amount of mass had disappeared, and an equivalent amount of energy had appeared. The sun's energy is believed to be created by a series of similar transformations.

History of the Atomic Bomb

"Atom" means indivisible, and for a long time the atom was regarded as the ultimate particle. Our present knowledge indicates that an atom consists of a central, massive, positively charged nucleus and planetary negatively charged electrons. The nucleus is made up of neutrons (no charge) and protons (positive charge), and an understanding of that combination has been the goal of the world's leading scientists. Some of the important contributions were as follows:

1919 Ernest Rutherford (English) caused transmutation of nitrogen into oxygen.
1932 Cockcroft and Walton confirmed Einstein's theory of energy creation.
1932 James Chadwick (English) discovered the neutron as a nuclear particle.
1934 Enrico Fermi (Italian) bombarded uranium with neutrons and apparently created a new, heavier, radioactive element (93).
1938 Hahn and Strassman (German) found that one of the products of uranium bombardment is barium—the atom had been split!
1938 Meitner and Frisch (German refugees in Copenhagen) explained Hahn and Strassman's work as nuclear "fission."
1939 Enrico Fermi pointed out "chain-reaction" possibility if fission of uranium by neutrons produces more neutrons.
1939 Potentialities of nuclear fission were mentioned frequently in newspapers.
1939 H. E. White mentioned "atomic bomb" in an elementary physics textbook.



Atomic Reactor in Operation

For the first time, the public had an opportunity to see a full-scale atomic reactor in operation at the International Conference on Peaceful Uses of Atomic Energy in Geneva, Switzerland, in August, 1955. Here visitors peer into the large tank of water in which the working part of the reactor is submerged. The glow is produced as a result of the excitation of the water molecules by fast neutrons released in the fission process. The rate of the reaction is controlled by the vertical rods extending down to the unit. (*Union Carbide Photo.*)

1940 Scientists voluntarily imposed secrecy because of war potential.
1941 Dec. 6. The United States authorized all-out effort to develop atomic weapons.
1945 July 16. First man-made atomic explosion took place at Alamogordo, N.M., after 4 years of work and expenditure of 2 billion dollars.

The Big Question

The story behind this brief listing is a fascinating illustration of scientific research aided by engineering know-how. It represents the cooperation of brilliant minds from all parts of the western world. Their work has developed a new source of energy of great scientific, social, and political significance. Whether or not it ultimately results in benefit to man remains to be seen.

STAGES OF ENGINEERING

Primitive man used just what was available, whereas the modern engineer starts with a need and develops a means of satisfying that need. In general, efforts at progress can be classified under four successive levels of activity: utilization, adaptation, conversion, and creation. Engineering, as we have defined it with emphasis on "applying science," is usually required in the last two stages.

For example, the fallen tree was "utilized" as a bridge and later "adapted" to house construction by setting a timber beam on two posts. In the simple truss, the timber was "converted" to a new form in order to take better advantage of its inherent properties. The alloy-steel cantilever bridge makes use of a material and a form which do not exist in nature but were "created" for the purpose.

Similarly we can imagine prehistoric man attracted by the tantalizing odor of a deer roasted in a forest fire and "utilizing" the result. "Adapting" fire to a convenient and controllable form of heat energy and making it a part of his daily living followed. "Conversion" of heat energy to the more useful mechanical form in the steam engine was a great accomplishment. At the highest level we could place the "creation" of electromagnetic energy in the form of intelligence to be broadcast to all parts of the world.

THE RATE OF ENGINEERING PROGRESS

We are so completely surrounded in our daily lives by the results of engineering achievement that it is difficult to realize that we are not at the zenith. Actually we are at an intermediate point on a curve which is rising ever more steeply.

In this brief review of the background of engineering only the highlights have been described. However, a quick look at the pattern of development as indicated by the dates mentioned reveals that the rate of engineering progress is ever-increasing, and the next few years are sure to bring a host of amazing developments.

To get a better perspective, let us suppose that scientific and engineering progress on the earth is being studied by a superior race located in another universe. Their astronomical situation is such that time is compressed and 1,000 years of our time is equal to one of their days. Going back into ancient history to the year 5000 B.C. would cover about a week of their time. If we tuned in on the Sunday morning broadcast, we might hear something like this:

> This is your Interstellar Reporter with the 11:00 A.M. round-up of this week's news. Last Sunday the following announcement was made:
>
> "Life has been observed on a medium-sized planet of one of the lesser solar systems. The most intelligent inhabitants live in caves and hunt other creatures for food. They use stone tools but are dependent on their own muscles for power. They understand the principle of the lever and have used fallen trees as bridges."
>
> Observers on Monday reported practically no change in the habits of the dwellers on what is called Earth.
>
> As our listeners will recall, the Tuesday broadcast referred to the progress of the Earth creatures. They had learned to build with timber and stone and had constructed with human power a tremendous pyramid of stone blocks in what is called Egypt. This was done with human power, but animals known as camels were being used as beasts of burden.
>
> Wednesday's observations revealed that wheeled carts had been devised and oxen were being used for power. The use of bronze tools represented a great advance.
>
> Thursday it was learned that iron tools had been used for the first time and tempering processes made possible strength and sharpness. Construction of canals and reservoirs was observed. The alphabet was invented late in the day, and written communication made easier.
>
> Friday the following announcement was made: "Geometry and accurate land measurements are being employed. The screw and the pulley have been invented, and a group known as Romans are constructing great roads and aqueducts. The stone arch is being employed for the first time, facilitating the construction of bridges, palaces, and cathedrals. Wood is becoming scarce in England, but the heating properties of coal have been discovered."
>
> Saturday a special investigating group reported an accelerated rate of progress. Algebra and trigonometry had become available as scientific tools. Magnetism and alchemy were being studied. Cast iron was available. Boats were improving rapidly, and the Earth creatures had learned to tack against the wind. Late yesterday afternoon the compass was invented.
>
> Today, Sunday, things are really happening fast. News bulletins are coming in every few minutes. The report of our Transportation and Power expert is as

follows: "Just before midnight an Italian sea captain made a trip to a sparsely inhabited continent called America. By 3 A.M. a mass migration to this new land of plenty was under way. At 7 o'clock this morning the steam engine was invented and immediately applied to manufacturing and land and sea transportation. By 9 A.M. the invention of the bessemer furnace had made available large quantities of steel. Portland cement, rubber, and oil came into general use. About 9:30 A.M. a cheap method of obtaining aluminum was perfected. Just before 10 A.M. an airplane carried man aloft for the first time. By 10:25 an American named Lindbergh had crossed the Atlantic Ocean by air. At 10:50 a military airplane flew nonstop completely around the Earth by refueling in flight. A bulletin just handed to me reveals that just a few minutes ago an airplane was flown faster than the speed of sound."

Here is the summary of the day's events as reported by our Electrical Observer. "At 6 o'clock this morning the similarity of electricity and lightning was established by a man experimenting with a kite. Around 8 A.M. the relationship between electricity and magnetism was formulated and the principles immediately applied to the arc-light generator and the electric motor. By 9:30 the incandescent light was invented, and the first central station was constructed soon afterward. Steam-generating stations and hydroelectric plants have been constructed, and now over 100 million horsepower serves the peoples of the Earth."

Our Communications Reporter notes the following: "Just before midnight last night the printing press was devised. This morning between 9 and 10 the typewriter and linotype machine became available. The telegraph and telephone were perfected about 9:30, and the first wireless message was sent soon afterward. Motion pictures were shown about 10 A.M. Radio broadcasting began at 10:15, and a television demonstration took place at 10:20. Color television broadcasts are under way now.

A late bulletin has just been handed to me. "Rapid progress is being made on the Earth toward the understanding of the structure of matter. At 10 o'clock this morning, Interstellar Time, an earth physicist proclaimed the theory that atoms are made up of heavy nuclei surrounded by orbital electrons. Shortly thereafter the Einstein theory of relativity was announced. At 10:35 atoms were being disintegrated by bombardment with neutrons. At 10:53 controlled nuclear fission had been perfected, and a series of atomic explosions have taken place, releasing tremendous amounts of energy."

There you have it. That's the news up to now.

Yes, that's the news up to now, but what's going to happen in the next hour, Interstellar Time, which means the next 40 years or so of our time? The conclusion that should be drawn is that the rate of scientific progress and engineering achievement is ever-increasing and probably there will be more new developments in the next 40 years than in the last 4,000. And the great contributions are going to be made by young men who, like yourselves, are just now starting out in engineering as a career. What will be your contribution?

ASSIGNMENTS

3-1. One great benefit from studying history is that reviewing what has gone before gives information regarding trends which can be used in predicting future developments. Select an engineering device which is important at the present time (automobile, airplane, office building, telephone, etc.) and gives promise of future development. Analyze its characteristics at the present time, and describe the changes which have taken place over some *specified* period of years. Predict its performance or characteristics at some *stated* time in the future.

3-2. Write a one-page discussion of the interrelationships among advances in theory, devices, materials, measurements, and fuels referred to in the section on Mechanical Engineering on page 56.

3-3. Select what you believe to be the outstanding technological development of the past 10 years. In a one-page report, discuss the events which led up to this development and point out what its effects will be on engineering and civilization in general.

3-4. It was pointed out in this chapter that efforts at progress can be classified under four successive levels of activity: utilization, adaptation, conversion, and creation. Cite a series of examples to illustrate how modern engineers are "creating" while earlier workers were limited to lower levels of activity.

4

ENGINEERING AS A PROFESSION

While the engineering profession is proud of its achievements in the past, of greater importance is what engineers are accomplishing today. Of even greater importance to the beginning student is what contributions he and other engineers of the future will be making in the years to come. The next four chapters are planned to provide a background for deciding where in engineering your interests may lie. First we shall look at the whole engineering profession in terms of technical organization, legal registration, and professional ethics. Then in Chap. 5 engineering will be classified by major branches and sub-branches and each branch will be discussed in detail. Chapter 6 will describe engineering in terms of functions, with comments on the different qualifications and training required for work in each. The relationship between engineers and their close associates the technicians and scientists will be explained in Chap. 7.

TECHNICAL ENGINEERING SOCIETIES

We have seen how civilization has been influenced by engineering achievements. The present form of the engineering profession reflects the same pattern of development. The rapid development of nuclear fission is an example of the way in which scientists, even in different countries, cooperate in bringing about progress. Two men in Germany repeated experiments made in Italy; their new discovery was interpreted by scientists in Denmark and carried to a meeting of physicists in America. This interchange of ideas among workers in a given field is essential. The modern organization which provides for sharing of ideas is called a technical society. A field cannot be said to be firmly established until a medium of this kind exists.

Formation of Engineering Societies

The first technical society in engineering was the Institute of Civil Engineers established in Great Britain in 1828. Its founding reflected the new importance of the "civil" engineer and may be said to mark the formal beginning of the engineering profession. Engineering, then, is a relatively new profession in comparison with ministry, law, medicine, and architecture.

The age of engineering in the United States dates from the founding of the American Society of Civil Engineers in 1852, little more than 100 years ago. This was a period of great activity in developing water power, surveying new regions, and building railroads and canals. Mining is one of the oldest engineering activities, and it was an important segment of the ASCE until 1871, when, with civil and mining fields expanding so rapidly, the American Institute of Mining Engineering was established. This later became the American Institute of Mining and Metallurgical Engineers, reflecting the increased stature of metallurgy.

As was pointed out previously, the Industrial Revolution created a need for specialists in power and machinery, and the professional requirements of these workers resulted in the American Society of Mechanical Engineers (1880). The rapid development of electricity as an important energy source and the need for interchange of knowledge in the new technology brought about the American Institute of Electrical Engineers in 1884.

The American Chemical Society had been founded in 1876, but the importance of chemistry in manufacturing and processing brought new problems, new methods, and new products. As would be expected, this called for the organization of chemical engineers into a tighter group, the American Institute of Chemical Engineers (1908). Paralleling the sequence of engineering development, the Institute of Radio Engineers was established in 1912, just 6 years after De Forest patented the three-electrode vacuum tube.

At the present time all work in nucleonics is under the control of the Atomic Energy Commission of the United States government. It directs the activities of hundreds of chemical, mechanical, and electrical engineers and performs many of the functions of a technical society. With the anticipated shift in emphasis from military to civilian applications of nuclear energy, we can expect to hear of the formation of a new institute to serve the special needs of "nuclear engineers."

Functions of Societies

How do the technical societies serve the engineering profession in general and their members in particular? The fundamental service is in providing for the exchange of ideas and information among workers in a

TABLE 1. TECHNICAL SOCIETIES

Since the technical society is based on serving special interests, a great many organizations have been established as special subfields have developed. This list is representative but not complete.

Acoustical Society of America
Institute of Aeronautical Sciences
American Society of Agricultural Engineers
American Institute of Architects
Society of Automotive Engineers
American Ceramic Society
American Institute of Chemical Engineers
American Society of Civil Engineers
American Concrete Institute
Associated General Contractors of America
National Association of Corrosion Engineers
American Society for Engineering Education
American Institute of Electrical Engineers
American Electrochemical Society
American Gas Association
American Society of Economic Geologists
American Association of Petroleum Geologists
American Society of Heating and Ventilating Engineers
National Home Builders' Association
Illuminating Engineering Society
Society of Lubricating Engineers
American Management Association
Society for the Advancement of Management
American Society for Testing Materials
American Society of Mechanical Engineers
American Society for Metals
American Institute of Mining and Metallurgical Engineers
Mining and Metallurgical Society of America
American Mining Congress
American Society of Municipal Engineers
American Society of Naval Architects and Marine Engineers
American Petroleum Institute
American Society of Photogrammetry
National Association of Practical Refrigeration Engineers
American Public Works Association
Institute of Radio Engineers
American Railway Engineering Association
American Society of Refrigeration Engineers
American Road Builders Association
Society for Experimental Stress Analysis
American Society of Tool Engineers
American Water Works Association
American Welding Society

specialized field. The one invention which probably contributed most to the advancement of science and engineering was the printing press. When information could be recorded and widely distributed, it was no longer necessary for each man to start out fresh in his search for knowledge; he could "stand on the shoulders" of those who had worked before him. So each society publishes a "journal," an account of the work of its membership.

Articles in the journal may be written solely for publication, or they may be "papers" presented at meetings and selected subsequently for publication. The second major activity then is the series of national, regional, and local meetings which are carried on by each society. These meetings feature discussions of established practice; presentation of new and perhaps controversial ideas; exhibits of novel devices, processes, or materials; visits to engineering projects and plants; and reports of committees assigned to study certain problems. In other words the meetings are for the purpose of keeping the engineer up to date with the developments in his specialty.

In addition, the technical societies are concerned with the professional status of the engineer and his education. One important activity is establishing and supporting "student chapters" wherein the engineering student interested in a certain branch is given an opportunity to become acquainted with engineers and their work. The student member receives the journal and is invited to attend the various meetings and field trips. The submission of student papers is encouraged and rewarded by recognition and, occasionally, prizes. One large society now publishes a student quarterly directed toward the interests of its student members. Participation in the chapter activities is of great benefit to the student because his interest is stimulated, his classroom study is motivated, he learns early what work in the field involves, and he makes acquaintances which will help him get started in the work of his choice.

Qualifications for Membership

The qualifications required vary a great deal from society to society; however, there are broad similarities. In general there are four grades of membership: Junior, Member, Associate, and Fellow. Junior membership ordinarily requires graduation from an accepted school of engineering or the equivalent in experience and is limited to those under a certain age (about 30 years). Full status as Member requires having been "in responsible charge of important engineering work" for a given length of time (3 to 5 years) and being qualified to "design and direct" such work. Certification as to these qualifications is given by society members who are personally acquainted with the applicant and his attainments.

Some societies confer the rank of Fellow upon a limited number of workers in the field whose accomplishments are outstanding and widely recognized. The rank of Associate is frequently an intermediate step for those who have passed the age ceiling for Junior but who have not yet the qualifications for Member.

REGISTRATION

In some European countries, membership in the professional society carries with it the license to practice in that particular branch. In this country, however, the power to license professional practitioners is vested in the states, and each state has its own law providing for the registration of professional engineers. The first registration law was enacted in Wyoming in 1907 as a result of the chaotic condition which developed when homesteaders "surveyed" their water rights and signed their own names as "engineers." In 1947 Montana became the forty-eighth state to provide for registration.

The purpose in registration or licensing is to protect the public by ensuring that those "professing" a knowledge of engineering science and skill in the art of applying it are competent to practice. The requirements for registration usually include being of good moral character, having satisfactorily practiced engineering in a responsible capacity for a stipulated length of time, and passing an examination of technical qualifications. In general, the examinations are designed to reveal if a person is qualified to plan, design, and supervise the construction or installation of engineering projects to provide safety, economy, and efficiency.

Only about half of those qualified are now registered in contrast to the 100 per cent registration of lawyers and doctors. The reason for this is that one does not have to be registered to practice engineering. Subordinates of a registered engineer are not required to register; a large office may comply with the law by having only its chief engineer registered. Officers and employees of the United States may practice engineering in connection with government service without being registered. Persons serving the engineering profession, rather than the public, by performing research need not be registered. Some states permit the practice of engineering as long as the person does not call himself an "engineer."

There are definite advantages in becoming registered. Some positions demand registration as a requirement for promotion. A contract involving payment of fees for engineering has no legal standing unless the engineer is registered. The Taft-Hartley law gives professional engineers certain rights in regard to collective bargaining. In most states, engineering plans cannot be accepted for official filing unless the signer is a registered engineer. It appears that the trend is toward making registration the accepted criterion for judging the professional engineer.

PROFESSIONAL ACTIVITIES

Much of the credit for engineering progress must go to the technical societies for their efforts in stimulating original work, providing for its presentation to interested audiences, and making it available in permanent form. However, the specialization of interest into numerous subbranches has been at the expense of the engineering profession as a whole. At the present time there is no organization which represents the 600,000 members of this largest of the professions.

There have been several attempts to unify the engineering profession. In 1920 the five major, or "Founder," societies formed the Federation of American Engineering Societies and set up the American Engineering Council. The AEC operated in Washington, D.C., and was making progress in representing the engineering profession in legislative matters until the depression resulted in loss of its financial support and it was finally abandoned completely in 1938.

The Engineers' Council for Professional Development was organized in 1932 to promote the professional growth of potential engineers from precollege counseling through college and first employment to full status as members of the profession. The ECPD now represents the five Founder societies, the American Society for Engineering Education, the National Council of State Boards of Engineering Examiners, and the Engineering Institute of Canada. One of its major functions is accrediting engineering curricula.

In 1934 the National Society of Professional Engineers was founded. Full membership is limited to those recognized by registration as professional engineers in the various states. With headquarters in Washington, D.C., the NSPE has been very active in representing the engineering profession, performing many of the services for which the AEC was established.

Another movement, initiated by the Founder societies in 1941, resulted in the creation of the Engineers' Joint Council. The purpose of the EJC is to "correlate the professional aims of the [Founder] societies and jointly to act for them on matters of national import affecting professional engineers."

The NSPE and the EJC worked together to secure in July, 1952, Congressional recognition of engineering as a profession. This resulted in professional engineers being placed on the same basis as members of the medical and legal professions in regard to wage and salary controls. More recently independent bargaining groups of engineering employees have organized the Engineers and Scientists of America, an engineers' union.

It is now clear that one characteristic of the strong but specialized technical societies is that they tend to produce a segmented engineering profession. One of the big problems facing professional engineers is how to preserve the advantages of the technical societies and still bring about a unified profession which does not exist at the present time. What would you suggest as a solution?

PROFESSIONAL ETHICS

Responsible engineers have long recognized the necessity for a statement of principles of professional practice which would serve as a guide in personal conduct. In 1906 the American Institute of Electrical Engineers appointed a committee consisting of President Schuyler S. Wheeler, H. W. Buck, and Charles P. Steinmetz to draw up a Code of Ethics. Similar groups representing other engineering societies have worked over the years to develop standards to meet the needs of their members. In 1950 the Engineers Council for Professional Development proposed the following statement which has been adopted by the American engineering community in general.

CANONS OF ETHICS FOR ENGINEERS

Foreword

Honesty, justice, and courtesy form a moral philosophy which, associated with mutual interest among men, constitute the foundation of ethics. The engineer should recognize such a standard, not in passive observance, but as a set of dynamic principles guiding his conduct and way of life. It is his duty to practice his profession according to these Canons of Ethics.

As the keystone of professional conduct is integrity, the engineer will discharge his duties with fidelity to the public, his employers, and clients, and with fairness and impartiality to all. It is his duty to interest himself in public welfare, and to be ready to apply his special knowledge for the benefit of mankind. He should uphold the honor and dignity of his profession and also avoid association with any enterprise of questionable character. In his dealings with fellow engineers he should be fair and tolerant.

Professional Life

Sec. 1. The engineer will co-operate in extending the effectiveness of the engineering profession by interchanging information and experience with other engineers and students and by contributing to the work of engineering societies, schools, and the scientific and engineering press.

Sec. 2. He will not advertise his work or merit in a self-laudatory manner, and he will avoid all conduct or practice likely to discredit or do injury to the dignity and honor of his profession.

Relations with the Public

Sec. 3. The engineer will endeavor to extend public knowledge of engineering, and will discourage the spreading of untrue, unfair, and exaggerated statements regarding engineering.

SEC. 4. He will have due regard for the safety of life and health of the public and employees who may be affected by the work for which he is responsible.

SEC. 5. He will express an opinion only when it is founded on adequate knowledge and honest conviction while he is serving as a witness before a court, commission, or other tribunal.

SEC. 6. He will not issue ex parte statements, criticisms, or arguments on matters connected with public policy which are inspired or paid for by private interests, unless he indicates on whose behalf he is making the statement.

SEC. 7. He will refrain from expressing publicly an opinion on an engineering subject unless he is informed as to the facts relating thereto.

Relations with Clients and Employers

SEC. 8. The engineer will act in professional matters for each client or employer as a faithful agent or trustee.

SEC. 9. He will act with fairness and justice between his client or employer and the contractor when dealing with contracts.

SEC. 10. He will make his status clear to his client or employer before undertaking an engagement if he may be called upon to decide on the use of inventions, apparatus, or any other thing in which he may have a financial interest.

SEC. 11. He will guard against conditions that are dangerous or threatening to life, limb, or property on work for which he is responsible, or if he is not responsible, will promptly call such conditions to the attention of those who are responsible.

SEC. 12. He will present clearly the consequences to be expected from deviations proposed if his engineering judgment is overruled by nontechnical authority in cases where he is responsible for the technical adequacy of engineering work.

SEC. 13. He will engage, or advise his client or employer to engage, and he will cooperate with, other experts and specialists whenever the client's or employer's interests are best served by such service.

SEC. 14. He will disclose no information concerning the business affairs or technical processes of clients or employers without their consent.

SEC. 15. He will not accept compensation, financial or otherwise, from more than one interested party for the same service, or for services pertaining to the same work, without the consent of all interested parties.

SEC. 16. He will not accept commissions or allowances, directly or indirectly, from contractors or other parties dealing with his client or employer in connection with work for which he is responsible.

SEC. 17. He will not be financially interested in the bids as or of a contractor on competitive work for which he is employed as an engineer unless he has the consent of his client or employer.

SEC. 18. He will promptly disclose to his client or employer any interest in a business which may compete with or affect the business of his client or employer. He will not allow an interest in any business to affect his decision regarding engineering work for which he is employed, or which he may be called upon to perform.

Relations with Engineers

SEC. 19. The engineer will endeavor to protect the engineering profession collectively and individually from misrepresentation and misunderstanding.

SEC. 20. He will take care that credit for engineering work is given to those to whom credit is properly due.

SEC. 21. He will uphold the principle of appropriate and adequate compensation for those engaged in engineering work, including those in subordinate capacities, as being in the public interest and maintaining the standards of the profession.

SEC. 22. He will endeavor to provide opportunity for the professional development and advancement of engineers in his employ.

SEC. 23. He will not directly or indirectly injure the professional reputation, prospects, or practice of another engineer. However, if he considers that an engineer is guilty of unethical, illegal, or unfair practice, he will present the information to the proper authority for action.

SEC. 24. He will exercise due restraint in criticizing another engineer's work in public, recognizing the fact that the engineering societies and the engineering press provide the proper forum for technical discussions and criticism.

SEC. 25. He will not try to supplant another engineer in a particular employment after becoming aware that definite steps have been taken toward the other's employment.

SEC. 26. He will not compete with another engineer on the basis of charges for work by underbidding, through reducing his normal fees after having been informed of the charges named by the other.

SEC. 27. He will not use the advantages of a salaried position to compete unfairly with another engineer.

SEC. 28. He will not become associated in responsibility for work with engineers who do not conform to ethical practices.

By studying the provisions of this statement you can learn a great deal about engineers, their activities, and their attitudes toward their chosen profession. Note the description of the engineer as a human being, an individual dealing with other individuals in a free society. Observe the emphasis on personal integrity in all relationships. How is this related to intellectual integrity in technical matters? Note the expressed intention of the engineer to place his professional conduct far above the requirements of the law. See how the engineer following the Code must place the honor of his profession before financial considerations.

PROFESSIONAL OBLIGATIONS

Of particular interest to you as a beginning engineer is the obligation of the experienced engineer to make available his knowledge to others. Only a minute part of your ultimate understanding will come as a result of your own original work; by far the greatest portion will be received from others —in school, through engineering societies, and from other engineers. In turn you will be obligated to make your contribution to the constantly expanding store of knowledge.

Engineering is more than an occupation; it is more than a vocation. Engineering is a way of life. As a young engineer you will be indebted to a host of pioneers, both renowned and anonymous, who have made the technical, professional, and ethical advances which have made engineering an honored and respected profession. The fruits of their efforts are available to anyone with the necessary aptitude who will seek them with proper diligence. The only payment expected is a dedication to the continuation, extension, and elevation of the profession of engineering.

ASSIGNMENTS

4-1. Select a technical society (other than the six discussed in this chapter) in which you might be interested in the future, and answer the following questions:

When was the society founded?

What technical developments led up to the founding of the society?

What contributions has the society made to engineering?

4-2. Select a technical society whose journal is in your school or public library. Study six recent issues of the journal, and answer the following questions:

What type of articles appear in the journal?

What topic is of greatest current interest?

Generally speaking, what positions are held by the authors of the articles in the journal?

4-3. Compare the requirements for membership in one of the five "Founder" societies with those for one of the other technical societies.

4-4. Study the legislative act under which professional engineers are licensed in your state. Determine the legal basis for licensing as carried on by your state, and summarize the requirements for licensing or registration as a professional engineer.

4-5. Study the Canons of Ethics for Engineers and answer the following questions:

If an engineer believes that a proposal made by the city engineer of his community is technically unsound, what course of action should he follow?

Suppose that an engineer is hired by a private firm to study a public engineering proposal which will require condemnation of some of the private firm's property. If his report is negative and is used by the firm to fight the proposal, what specific statement should appear in the report?

Suppose that an engineer has been serving a small manufacturing company on a part-time basis as a sales engineer, proposing and designing installations of the company's product, boilers, on commission. If he is requested by a firm considering the installation of a new power plant to act for them as a consulting engineer, what limitations are placed on his actions and compensation by the rules of ethical conduct?

5

BRANCHES OF ENGINEERING

One justification for a book describing the nature of engineering is that this broad field of knowledge covers so many diverse activities. As indicated in Table 2, one classification of engineering is in terms of major and minor branches, each branch being concerned primarily with a particular type of product, process, or project. In many cases, arbitrary decisions have been made regarding which shall be called major branches and which sub-branches and where a given specialty shall be listed. It must be realized, however, that there is a great deal of overlapping, and no engineer can afford to be content with training in a single field of specialization.

The branches of civil, mineral, mechanical, electrical, and chemical engineering are described in detail, and the distribution of engineers by industry within the field given. The work done in certain sub-branches is discussed, and possibilities for the future indicated. The other branches are defined only briefly.

CIVIL ENGINEERING

We have seen that civil engineering occupies a position of prominence in the history of engineering. At the present time nearly one-fourth of all engineers are engaged primarily in this branch.

The Work of the Civil Engineer

The breadth of civil engineering is shown by the wide range of topics included in the tabulation of sub-branches. As indicated by Table 3, however, nearly two-thirds of all civil engineers are associated with the construction industry. Approximately 40 per cent of all civil engineers are concerned with the construction of buildings, highways, and bridges. In other words, while this branch is very broad, the great majority of civil engineers are engaged in work connected with a few major types of projects.

TABLE 2. CLASSIFICATION OF ENGINEERING BY BRANCHES AND SUB-BRANCHES

Civil Engineering

Airport	Geology	Photogrammetry	Foundation and soil mechanics
Architecture	Highway	Power	Reclamation and irrigation
Bridge	Hydraulic	Railroad	Sanitation and sewage
City planning	Materials	Structural	Surveying and mapping
Construction	Municipal	Tunnel	Waterways, rivers, and harbors

Mineral Engineering

Mining	*Metallurgy*	*Petroleum*	*Ceramics*
Coal	Beneficiation	Development	Abrasives
Metals	Ore processing	Exploration	Cement
Nonmetals	Extractive metallurgy	Oil production	Clay
Exploration	Physical metallurgy	Transportation	Enamels
Development	Powder metallurgy	Storage	Glass
Geophysical	Casting	Pipeline	Refractories
Safety	Welding	Refining	Kilns

Mechanical Engineering

Aeronautic	Flight test	Machine tool	Heating and ventilating
Aerodynamic	Heat transfer	Power plant	Farm machinery
Air conditioning	Industrial	Refrigeration	Instrumentation and control
Automotive	Jet engine	Rocket	Internal combustion
Combustion	Lubrication	Steam	Materials handling
Diesel	Machine design	Turbine	Military equipment

Electrical and Electronic Engineering

Apparatus	Motion picture	Illumination	Propagation
Machinery	Power generation	Electroacoustics	Radar
Corrosion control	Power transmission	Electron ballistics	Radiation
Electricity and magnetism	Power distribution	Electron optics	Radio
Instrumentation	Servomechanism	Geophysical	Television
Control	Telegraph	Navigation aid	Telemetering
	Telephone	Electrochemical	Test equipment

Chemical Engineering

Electrochemical	Petroleum	Absorption and adsorption	Contamination
Food processing	Rubber	Heat transfer	Corrosion
Heavy chemicals	Soaps and fats	Materials handling	Process design
Paper and pulp	Synthetic fibers	Size reduction	Separation

Other Engineering Branches

Agricultural	Geological	Military	Naval architecture
Acoustical	Marine	Nuclear	Ordnance and armament

TABLE 3. DISTRIBUTION BY INDUSTRY OF 8,540 CIVIL ENGINEERS SURVEYED IN 1946*

Construction		65.0%
Bridges	7.5	
Buildings	18.3	
Highways	14.3	
Sewerage	4.0	
Surveying	3.8	
Waterways	4.2	
Water works	3.3	
Other construction	9.6	
Manufacturing		7.4
Transportation		4.2
Utilities		9.1
Education and personal services		7.4
Other industries		6.9
Total		100.0%

* Andrew Fraser, "The Engineering Profession in Transition," Engineers Joint Council, New York, 1946.

Buildings, Bridges, and Other Structures

The largest single group of civil engineers is concerned with the design and construction of commercial, industrial, and public buildings and bridges, dams, towers, tanks, etc. These are built of steel, reinforced concrete, timber, earth, brick, and aluminum in a great variety of forms including columns, beams, girders, trusses, arches, and slabs. The structures must carry their own weight plus that of their intended loads; in addition they must withstand earthquakes, vibrations, wind pressures, and snow loads. In their construction the engineer makes use of cranes and hoists; machinery for making, placing, and finishing concrete; equipment for welding and riveting; and a great variety of skilled craftsmen blended into an efficient team.

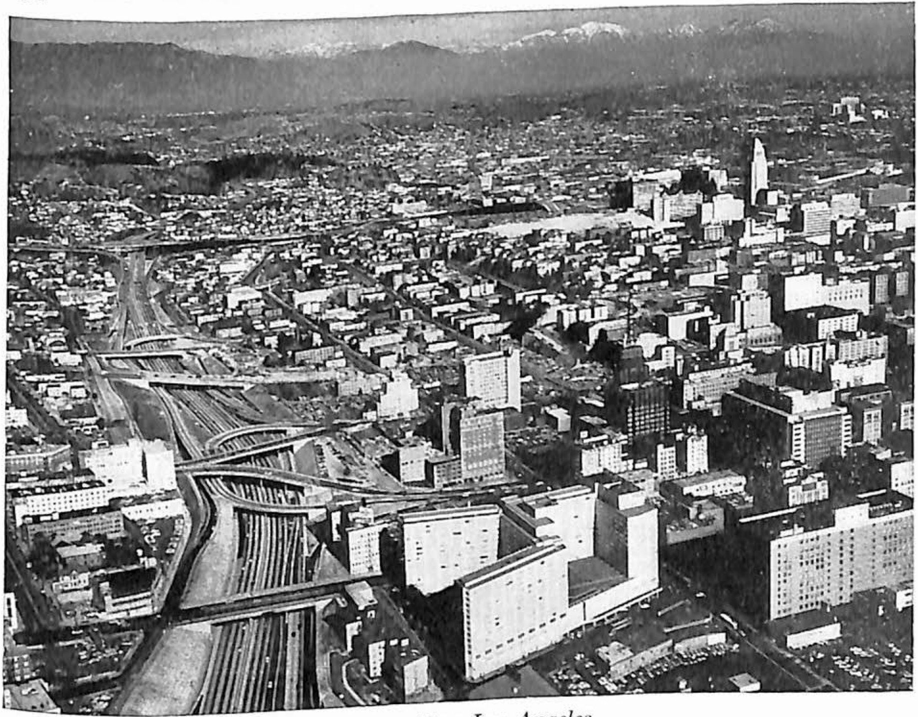
Highways, Airports, and Railroads

In each of these sub-branches there is need for economic studies of population to be served, potential traffic, and possible site locations. Layout requires topographic surveys, soil surveys, and data on land costs. Design requires knowledge of soils, foundations, structures, construction materials, and drainage systems. The design must be economical in maintenance as well as in first cost.

Hydraulics—Water Supply, Irrigation, and Sanitation

Hydraulics has to do with the control, utilization, and conservation of water and other liquids and gases. Hydraulic engineering includes flood control, irrigation, storage, hydroelectric power production, reclamation, municipal water and sewage systems, pumping machinery, hydraulic power transmission, navigation, and recreation.

Reclamation includes design and construction of water-supply systems to make arid lands usable and of drainage systems to remove excess water from potentially agricultural lands. Irrigation has to do with the economic application of water to the land after it has been made available.



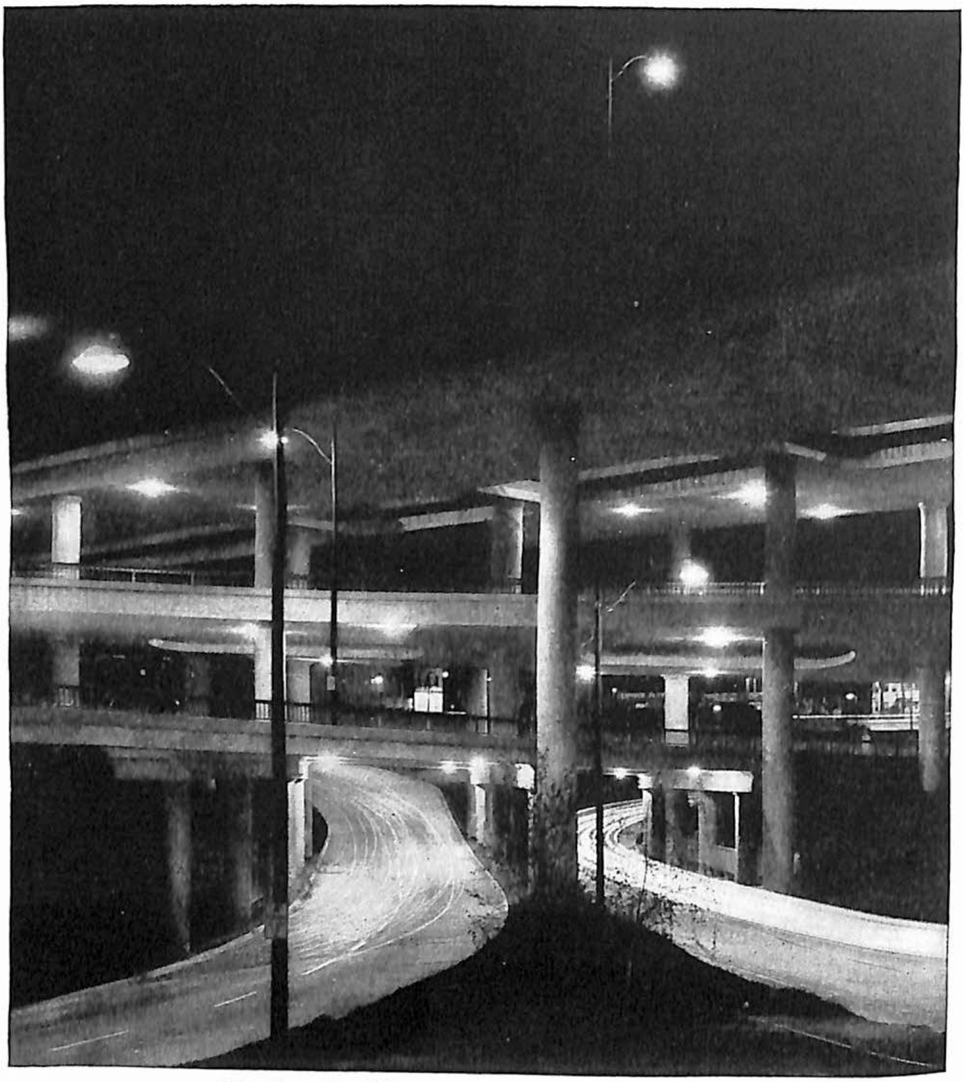
Metropolitan Los Angeles

Every great city provides hundreds of examples of the important contributions of civil engineers. In this picture are illustrations of architectural, bridge, city planning, construction, flood control, geological, highway, hydraulic, municipal, railroad, sanitation, structural, transportation, and water supply engineering. On the left is the Harbor Freeway which provides a link between Pasadena and Glendale on the north with the harbor cities of Long Beach and San Pedro on the south. (*California Division of Highways.*)

Sanitation engineering involves the application of engineering knowledge and techniques to the prevention of disease and the promotion of good health. It is concerned with water supply, sewerage, waste disposal, water and air pollution, food production and distribution, and health and safety aspects of housing—plumbing, ventilation, and heating.

Illustrative Civil Engineering Project

The results of civil engineering can be typified by the Empire State Building, the Los Angeles Freeway system, and the Golden Gate Bridge,



The Four-level Freeway Structure in Los Angeles

This unique example of the highway engineer's art is at the junction of the Harbor Freeway (page 47) and the Hollywood Freeway. This structure is essentially a group of continuous reinforced-concrete box-girder bridges supported on round concrete columns and footings, some of which are "spread" footings and some are pile supported. The spacing of the columns to accommodate all four decks was a complicating factor in the design. (*California Division of Highways.*)

but in looking at the finished structure it is hard to see the actual work of the engineer. That work can be considered in terms of five phases: *conception, preliminary survey, design, construction,* and *operation.* Consider, for example, the so-called Reber Plan for transforming the San Francisco Bay. This plan calls for earthen dikes creating fresh-water lakes in the present north and south bays and provision for carrying water from the Sacramento and San Joaquin Rivers to the south lake. According to its backers, the 250-million-dollar project would provide highway and railroad facilities across the Bay, room for airports, fresh water for irrigation, expanded docking facilities and would create 20,000 acres of new and valuable land.

The project has passed the *conception* stage, but an adequate *survey* has not been made. There have been numerous lengthy hearings before various public boards, and many persons, engineers and otherwise, have expressed their opinions. Recently an appropriation of $200,000 was set up to provide for a complete engineering survey of the project. Questions to be answered include: What would be the effect of the dikes on tidal flow, shoals outside the Golden Gate, sewage systems, etc.? What would be the rate of evaporation from the lakes, and how would it affect the storage of fresh water? How long would it take for the present marshes to become salt-free and usable? What type of structures would be most economical, and how does the total cost compare with the future benefit?

When answers to these and many other questions are available, a decision can be made as to whether all or part or none of the project should be initiated. The third stage, *design,* would involve specialists in dams, highways, bridges, docks, waterways, etc. *Construction* would probably be done by a group of organizations, each with extensive experience in certain fields. Upon completion, *operation* of the entire project would be turned over to a specially constituted group similar to the Toll Bridge Authority of California or the Tennessee Valley Authority. In all these phases, the civil engineer would be making his contribution.

The Future of Civil Engineering

Civil engineering in the first half of the twentieth century has, in a sense, been a matter of theory catching up with practice. Dams were built long before there was any quantitative knowledge of their behavior; truss analysis was formulated after trusses had been in use. Understanding has made possible bigger and more efficient structures which are basically similar to those of hundreds of years ago.

The development of great concentrations of population, the mass use of the automobile and the airplane, and the demands of industry for great quantities of power present the civil engineer with a series of problems. To supplement reinforced concrete, alloy steels, and light metals, he must develop new materials and adapt them to economical construction. He must develop more efficient methods of placing concrete, fabricating structural elements, and applying attractive finishes. He must learn more about prestressing and continuity, about rainfall and runoff, about economics and financing, about regional planning and prevention of blight in large cities. He must solve pressing problems in mass transportation, waste disposal, water supply, and civil defense. Certainly the future calls for new men with new vision.

MINERAL ENGINEERING

Our modern civilization requires a continuous supply of products from two basic industries, agriculture and mining. As you look around your room, practically everything in sight started out as an agricultural product or was dug out of the ground. While mining and metallurgy are among the oldest of the engineering arts, their development through ancient and modern times has led to confusion regarding the activities of the engineers in this broad category. To clarify the situation for the beginning student, let us apply the term "mineral engineering" to the general category and define the subdivisions as follows:

*Mining engineering** includes the exploration, location, development, and working of mines for extracting fuels such as coal, lignite, and oil shale; metallic ores such as copper, iron, lead, gold, silver, tin, and zinc; and other minerals such as asbestos, bauxite, borax, potash, and sulfur.

*Metallurgical engineering** includes production of metals from ores by mechanical, thermal, and chemical processes; development of metallic alloys with needed characteristics through knowledge of molecular and crystalline structure; and fabrication of metal products by casting, welding, and powder metallurgy.

*Petroleum engineering** includes exploration, drilling, production, storage, and transportation of crude petroleum and natural gas.

*Ceramic engineering** includes preparation of nonmetallic minerals from raw materials; forming by presses, molds, and wheels; firing in kilns, ovens, and furnaces; and application to industrial and domestic uses.

MINING AND METALLURGICAL ENGINEERING

Mining and metallurgical engineers are closely related by tradition, but their work is quite separate. The total number of engineers in this category is small, and in discussions they are grouped together.

Mining Engineering

The old-time prospector with his donkey, pan, pick, and shovel is nearly gone from the mining picture. He was limited to following clues which appeared on the earth's surface. Modern exploration to find hidden deposits requires scientific training and elaborate equipment such as seismograph, geophysical apparatus, microscope, transit, truck, helicopter, and even Geiger counter.

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* American Society of Mechanical Engineers, "Definitions of Occupational Specialities in Engineering," New York, 1951.

After the location of an ore deposit is determined, the earth must be "opened up" to discover the nature, extent, and value of the deposit. If the project appears economically feasible, then expensive equipment is brought in to bring the ore to the surface for further treatment. Opening up and removing the ore involve high explosives, power tools, complex machinery, rapid materials handling, elaborate safety precautions, and constant attention to costs. It should be clear that the mining engineer depends on the knowledge and techniques of the civil, electrical, and mechanical engineer; the geologist; and the chemist in addition to those of his own specialized field.

Open-pit Copper Mining, Chuquicamata, Chile

The mining engineer usually works in remote areas far from civilization, and his achievements are frequently hidden away under ground. Here is a huge deposit of relatively low-grade copper ore which has been opened up for exploitation. Powerful shovels load trains of ore cars operating on different levels or "benches." The ore is concentrated by "flotation" and then smelted in roasting furnaces. For most purposes copper must be very pure and the final refining is done electrolytically. (*Chile Exploration Company.*)

TABLE 4. DISTRIBUTION BY INDUSTRY OF 2,825 MINING-METALLURGICAL ENGINEERS SURVEYED IN 1946*

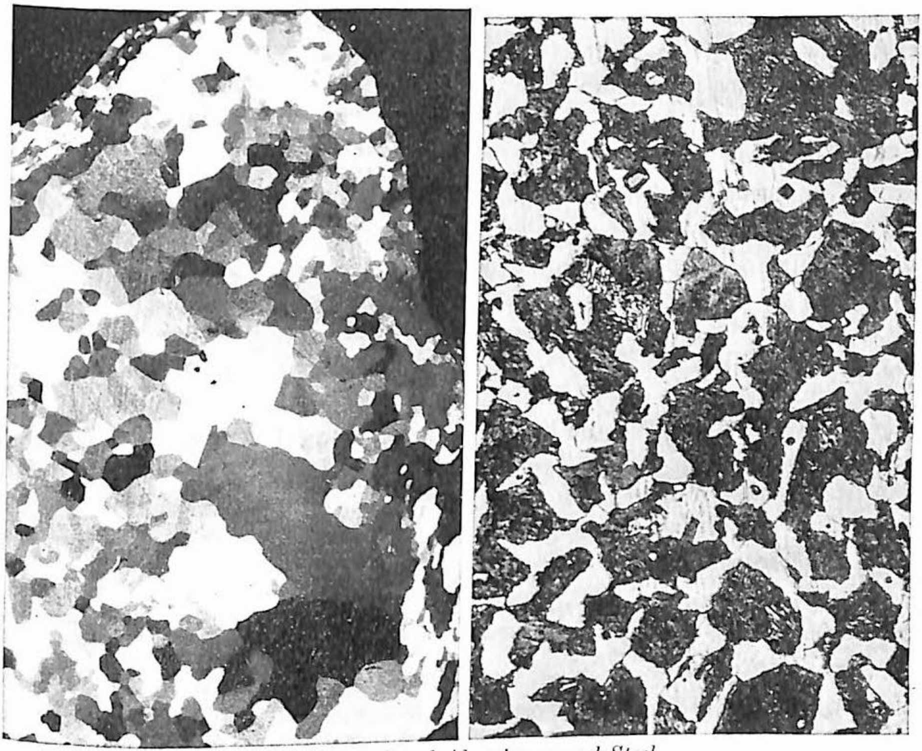
Mining		55.6%
Coal	9.9	
Ferrous	4.7	
Nonferrous	23.3	
Crude petroleum and natural gas	10.7	
Other mining	7.0	
Manufacturing		35.6
Iron and steel and products	14.5	
Nonferrous metals and products	13.6	
Machinery and equipment	4.2	
Petroleum and coal products	0.9	
Other manufacturing	2.4	
Education and personal services		5.4
Other industries		3.4
Total		100.0%

* Andrew Fraser, "The Engineering Profession in Transition," Engineers Joint Council, New York, 1946.

Metallurgical Engineering

In general there are two broad areas of activity: *extractive* and *physical* metallurgy. The extractive metallurgist is concerned with the recovery of metals from their ores and their further refining; output of the mine becomes the raw materials for the extractive metallurgist. He first uses various mechanical means to remove the metallic ore from the undesirable accompanying material, a process that is called ore dressing, or "beneficiation," meaning "to make better." The location of the beneficiation process and the extent to which it is carried are based on economic considerations. Next the extractive metallurgist must separate the metal from the chemical compounds in which it exists in the ore and obtain commercially pure metal. Pyrometallurgy involves the use of fire as a roasting, melting, or reducing agent as in the blast furnace. Electrometallurgy is employed in the production of aluminum and in the purification of copper.

The physical metallurgist then takes over and puts the refined metals to use. He is concerned with making alloys which will yield improved physical properties: high-strength steel, stainless steel, low-melting-point solder, corrosion-resistant bronze, high-permeability iron, and easily machined cast iron. Foundry work is a special field of physical metallurgy which involves choice of furnaces, metals, molding sands, and core materials. Forging and welding have benefited from the work of the metallurgist in alloying, physical testing, and heat-treating. Heat-treatment is an example of how the engineer can convert given materials to more useful forms. Starting with a given combination of iron, carbon, and minor alloying elements, the metallurgical engineer can, by specifying the rates and degrees of heating and cooling, obtain extreme hardness *or* toughness, machinability *or* resistance to abrasion, strength *or* ductility. By this art the range of properties of engineering materials has been extended greatly.



Metallography of Aluminum and Steel

The aluminum (left) is nearly pure, photographed approximately actual size after etching to bring out the crystalline structure. The alternate dark and light areas are differently oriented grains. (*Dr. Ralph Parkman.*)

On the right is SAE 1042 (containing 0.42% carbon) hot-rolled steel at a magnification of 200×. The light areas are *ferrite*, a relatively soft solid solution of iron and carbon. The dark areas are *pearlite* (so-called because it resembles mother-of-pearl) consisting of alternate layers of ferrite and the very hard and brittle compound *cementite* (Fe_3C). The metallurgist can control the distribution of the carbon and the size of the grains and in that way determine the physical properties of the metal. (*Prof. James H. Anderson.*)

Future of Metallurgy

While metallurgy is one of the oldest arts, it is one of the youngest sciences. Working with high-power microscopes, X-ray diffraction units, spectrographs, and electron microscopes, metallurgists have gained an understanding of the crystalline structure of metals as related to physical properties. Soon alloys will be made "to order" with high strength, light weight, resistance to corrosion, and resistance to high temperatures.

PETROLEUM ENGINEERING

In this discussion the refining and manufacturing of petroleum and its products will be considered later as a part of chemical engineering, since the great majority of men in this field are chemical engineers. Petroleum engineering as used here has to do with exploration, drilling, production, storage, and transportation of crude petroleum and natural gas.

Background History

The first American use was in the Pittsburgh area around 1855 when "rock oil" was collected as an impurity of salt wells and sold as an all-around cure—a competitor of "snake oil." Limited amounts of crude oil had been used for lighting, but the drilling of the famous Drake oil well in western Pennsylvania in 1859 marks the beginning of the petroleum industry. At a depth of 70 ft sufficient oil was found to pump 20 bbl a day. Curiously enough, kerosene for illumination was the desired product and gasoline was an undesirable by-product of the first crude distilleries.

One theory of the origin of petroleum is that it is part of the remains of multitudes of microscopic sea animals. It is found trapped under folds (anticlines) or domes of nonporous rock layers. Usually the oil-bearing sand lies above a salt-water area, and above the oil is found a gas pocket.

Work of the Petroleum Engineer

The location and mapping of possible oil-bearing formations are usually done by geological and geophysical methods using highly scientific instruments. The petroleum engineer must decide if, where, and how to drill the well or wells. The design of drilling equipment is an important responsibility. As the hole is drilled, provision must be made to prevent such occurrences as too rapid wear of the bit, caving in of the walls, intrusion of water, deviation of the size and/or direction of the bore, and sudden blowouts due to high gas pressure. The great need for skill and judgment is obvious when it is considered that the work of drilling is out of sight—perhaps 4 miles underground. Core samples are taken at suitable intervals, and electric logging instruments are used during the drilling, but the petroleum engineer cannot go down into the "mine" for a look around.

After the drilling has penetrated into the producing formation to the optimum distance, the well may be "shot" by high explosives to increase production. If natural pressure is insufficient to raise the oil to the surface, suitable pumping means must be selected and installed. Pumping methods, pumping rates, well spacing, and artificial injection of gas, air, or water are carefully controlled in order to conserve reservoir energy and ensure maximum recovery of oil. Most oil fields are operated under government regulation, and frequently several companies combine in a "unit operation."

The crude oil may be stored locally or sent directly to refineries. Transportation may be by pipeline, tank car, tank truck, or marine tanker. All transportation and storage operations require elaborate safety provisions to prevent breaks or fires. Today there are over 125,000 miles of pipelines, some over 1,000 miles long. Pipelines carry crude oil from Texas to Pennsylvania and natural gas from Oklahoma to California.

Future of the Petroleum Industry

In less than 100 years, petroleum has become a vast industry of worldwide scope and international importance. The major contribution to this development has been by American engineers and businessmen. While gasoline is the most important product at present, it is recognized that petroleum is a complex raw material which, in the hands of the chemical engineer, may be turned into an endless variety of useful products. Oil is a natural resource without which no large nation can survive, and its discovery, production, and processing will become increasingly important.

CERAMIC ENGINEERING

The early use of fired clay for vessels, bricks, art work, and permanent records shows that ceramics is one of the oldest engineering fields. The term "ceramic" is applied to the products obtained by high-temperature processing of nonmetallic minerals. Included are such diverse items as dinnerware, spark plugs, home insulation, glazed structural tile, grinding wheels, jet-engine parts, firebrick, plaster, and window glass. Obviously this field is important in our industrial and domestic life.

Work of the Ceramic Engineer

The ceramic engineer is concerned with grading, grinding, and mixing raw materials; forming desired shapes on potter's wheels and in molds and presses; and firing the product at high temperature in kilns and furnaces. The machines and methods for carrying on these processes include applications of various mechanical, electrical, and combustion equipment. The engineer is responsible for designing and operating the equipment, testing the products, and carrying on research in raw materials, processes, and products.

Abrasives, used for grinding and polishing, employ natural materials such as emery, corundum, and garnet and artificial materials such as silicon carbide and fused alumina. *Structural clay products* include common brick, glazed and unglazed tile, sewer pipe, and special brick. The clay is mixed with water, formed, dried, and then fired to develop strength and durability. *Whiteware* includes glazed or unglazed china, porcelain, and earthenware, used for kitchenware, art objects, sanitary ware, tile, and electrical insulators. *Refractories* are ceramic materials which resist melting and therefore are useful in furnace construction and engine exhausts. *Glass* is an inorganic product which has cooled without crystallizing. Its outstanding characteristics are hardness and transparence, although it may be opaque or colored or in the form of flexible fibers. *Cements* include portland cement (used in concrete), asphaltic cement, limes, and plasters.

Future of the Ceramic Field

Until recently ceramic work was strictly an art with very little science. The ratio of engineers to skilled workers in ceramics is low compared with other industries. However, the increased demand for ceramic items and the rapid development of new products have resulted in more emphasis on mass production. The introduction of modern machinery has increased the need for technically trained personnel, and the outlook for ceramic engineers is very favorable.

MECHANICAL ENGINEERING

The work of the mechanical engineer is probably more familiar to the general public than that of any other, with the possible exception of the civil engineer. The material side of our twentieth century progress is full of illustrations of the mechanical engineer's skill in converting material and energy into desirable things. From the time of the Industrial Revolution, the mechanical engineer has been concerned with developing sources of power ("engines"), applying the power to mass production by "machines," and devising methods of utilizing heat and cold ("heat transfer").

Engines

We shall use the term "engine" here to mean a device for converting the chemical energy of a fuel into kinetic energy of motion, as in the steam engine or the automobile engine.

Steam. When a fuel is burned in a boiler or steam generator, its chemical energy is converted to thermal energy in the flame, and that in turn is transferred to the water or steam. The energy of the steam is converted to mechanical work in a reciprocating engine or in a rotating turbine. The mechanical energy may be used directly or converted into electrical energy for transmission elsewhere.

Internal Combustion. If the fuel is burned within the device itself, it is called an internal-combustion engine. The most important of these are the Otto cycle engine (as in the automobile), diesel cycle engine, gas turbine, jet engine, and rocket motor. The engineer is concerned with fuels, fuel injection and ignition, cylinder-piston-valve combinations, exhaust systems, pumps, cooling-water supply, lubricating systems, and instrumentation.

Machines

Power is valuable when it is used to drive machines which produce desired results. The approach to contriving the machine depends on its intended application.

TABLE 5. DISTRIBUTION BY INDUSTRY FIELD OF 8,776 MECHANICAL ENGINEERS SURVEYED IN 1946*

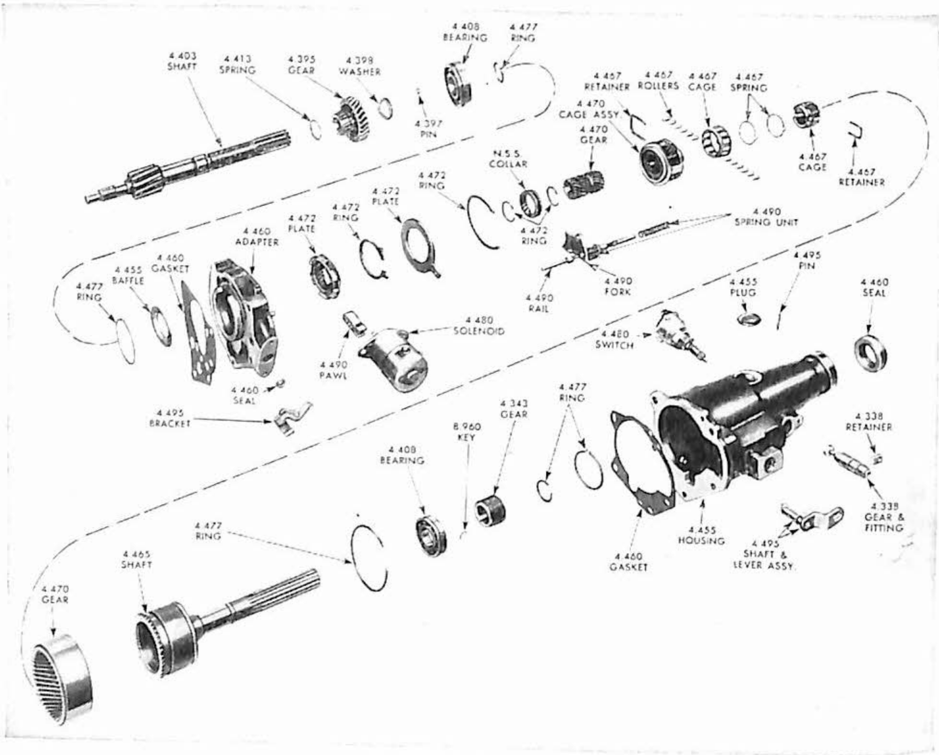
Manufacturing		67.6%
Transportation equipment	20.4	
Machinery	19.5	
Metals and products	8.7	
Chemicals and products	3.2	
Petroleum and coal products	2.9	
Food and textiles	2.5	
Lumber, furniture, and paper	2.1	
Rubber, stone, clay, glass	1.9	
Other manufacturing	6.4	
Government		10.5
Utilities		3.5
Transportation and communication		3.2
Construction		2.5
Other industries		12.7
Total		100.0%

* Andrew Fraser, "The Engineering Profession in Transition," Engineers Joint Council, New York, 1946.

Machine Design. In designing an automatic peach peeler, the problem is one of invention, creation of a clever device which will work better, faster, and more safely than the hand-held knife. In contrast, the design of an airfoil section to provide certain lift and control characteristics at supersonic speed must be based upon highly scientific aerodynamic theory and precise data. Design of an automobile body necessitates taking into account the vague factor of style as well as specific factors of strength and rigidity. The machine designer works with power-transmission elements such as shafts, gears, and torque converters; actuating mechanisms such as valves, levers, and cams; and structural elements such as fasteners, supports, and bearings.

Machine Tools. Of the greatest importance are those tools which rapidly and precisely fabricate machine parts from raw materials. These include lathes; shapers; grinders; milling, drilling, and boring machines; and the associated cutters, dies, jigs, and fixtures. Mechanical engineers have responsibility for design, production, and application of machine tools and also the study of cutting and abrasive action, lubricants, and coolants.

Machinery. The machines created by mechanical engineers find application in mines miles below the earth's surface as well as in aircraft miles above it. Printing presses, linotype machines, textile looms, sawmills, cultivating and harvesting machines, concrete mixers, office machines, and home appliances indicate the tremendous variety of laborsaving devices which have contributed to this country's standard of living.



Exploded View of Torque Converter Component

Mechanical engineers are concerned with development, transmission, and use of mechanical power. In this view of a portion of an automobile transmission we see the results of mechanical engineering; design of gears for function and strength, research in metallurgy and lubrication, heat treating of bearings for extreme hardness, production of rigid cast-iron housing, and graphic representation to facilitate assembly. (*General Motors Corporation.*)

Materials Handling. One type of machinery is becoming so important that it merits special mention. In manufacturing, storage, and transportation, equipment is needed to handle items and materials on an occasional or continuous basis. Included are cranes, conveyers, chutes, pipes, pumps, bulldozers, tractors, and lift hoists. The design, production, and application of this type of machinery have been a special field of mechanical engineering which can result in great economies.

Transportation

Mechanical engineers are concerned with practically every inanimate thing that moves. Of particular importance, in terms of numbers of mechanical engineers employed, is the group of machines which move and carry people or other things—vehicles of land, sea, and air. Formerly the railroad and shipbuilding industries dominated transportation, but at present the number of engineers employed in these industries is small compared with those in the automotive and aircraft industries.

Automotive. From about 4,000 in 1900, annual production of cars and trucks climbed to nearly 1 million in 1916. In 1955 approximately 9 million automotive units were produced. First the rich man's luxury, then the working man's necessity, now the automobile has become a part of our mode of existence, and the number of two-car families is rapidly increasing.

Behind this multibillion-dollar output are dozens of assembly plants, many major manufacturing plants, and hosts of small and large suppliers of component parts. Mechanical engineers are active in design, production, and testing capacities at all stages of manufacture. Because of the intense competition in the automotive industry, large numbers of engineers are engaged in research and development of more powerful and more efficient engines, automatic transmissions, power-actuated auxiliaries, smoother riding suspensions, and comfort-providing accessories.

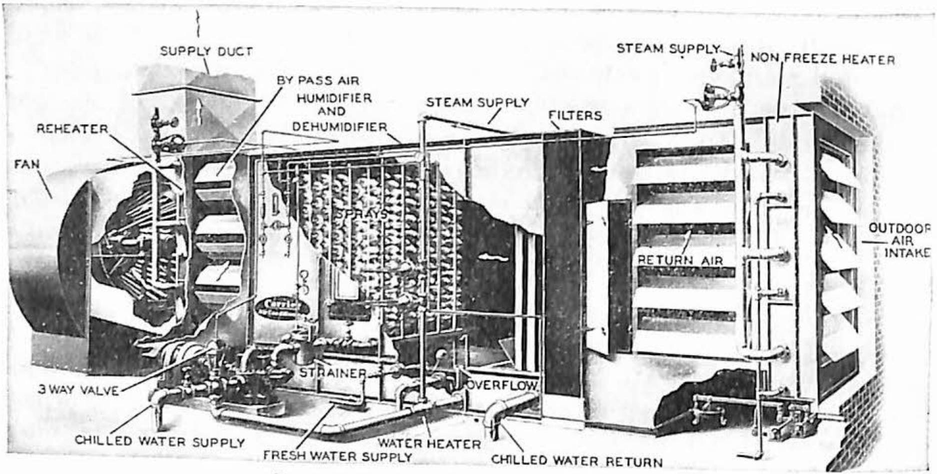
Aircraft. During World War II and then again after the Korean outbreak the aircraft industry expanded greatly as a result of military appropriations. Civil aeronautics also benefits from the technological advances made under the stress of defense preparation, and the present rate of increase in air transportation can be expected to continue as man strives to shrink the earth and pull the planets into his own sphere.

In 1946, about one out of every six mechanical engineers was employed in the aircraft-manufacturing industry. At present, the largest numbers of engineers are active in design and development of new aircraft, with smaller numbers engaged in production, operation, and maintenance. Aeronautics is such a new field that the technology is constantly changing and engines, aerodynamic structures, and operating controls are subjected to constant experimenting. Probably refinement of design is carried further in aircraft than in any other branch of engineering because of the great importance of providing high performance, safety, and light weight under conditions of extreme acceleration, speed, and temperature.

Heat Transfer

It has been said that the only difference between the poor man and the rich man was that the rich man had his heat in the winter and ice in the summer. Since the time of the steam engine, the production, transformation, and application of heat energy has been the concern of the mechanical engineer.

Heating and Ventilating. The conversion of fuels to heat is carried on in furnaces and ovens for all types of industrial and domestic purposes.



Central Station Air-conditioning Unit

This type of unit is used to provide clean air of the proper temperature and humidity to all parts of an office building. A mixture of *outdoor* and *return air* is drawn in at the right and passed through *filters* to remove dust, smoke, and pollen. The temperature of the water in the *spray chamber* determines the moisture content or humidity of the air. The air, further cleaned by the sprays, is then brought to the proper temperature by the *reheater* and distributed through the *supply duct* by the *fan*. The mechanical engineer's job would include: determining the building requirements, selecting the heating, cooling, and humidifying processes, calculating sizes of piping and duct work, heat-transfer surfaces, heating and chilling requirements, and preparing detailed plans and specifications on major components and auxiliaries. (*Carrier Corporation.*)

Heat is a valuable ally in metallurgy, ceramics, heat treating, and refining as well as a comfortable friend in the home. Since the distribution of heat in the form of warm air requires the same type of blowers and ductwork as does the removal of undesirable odors and poisonous fumes, these two fields are usually linked. Of necessity the heating engineer must also be skilled in the application of insulation to keep the heat where it is wanted.

Refrigeration. When heat is removed, we have cooling, which is frequently done by refrigeration. The most common domestic refrigerators employ the compression method in which a refrigerant is compressed by mechanical means, cooled in an exterior condenser, and then expanded rapidly, causing it to absorb heat from the food-storage compartment. Refrigeration is used in food storage, food preservation, industrial processing, and air conditioning.

Air Conditioning. Human comfort depends upon physiological and psychological factors. The mechanical engineer possesses the knowledge and has available the machinery for controlling at least one part of man's environment. Air conditioning refers to the simultaneous control of air temperature, humidity, movement, and purity. Air-conditioning systems include heaters, refrigerators, washers, filters, blowers, ductwork, and controls.

The Future of Mechanical Engineering

It appears from the foregoing that mechanical engineering* is the most varied of engineering fields and possesses unlimited potential for development. The automotive and aeronautical industries are tremendous segments of our national economy which have not yet reached their full growth. Other smaller industries show just as much promise. Existing industries may be completely overhauled to take advantage of "automation," the reduction of a whole series of complex processes to completely automatic operation. In addition the advent of new sources of energy, new materials, and new products will create whole new industries undreamed of at the present time.

ELECTRICAL ENGINEERING

The electrical industry was founded on the basis of two unique properties of electricity—the ability to travel great distances along a wire and the ability to provide a bright light without combustion (incandescence). Of greater importance at the present time are the ease and efficiency with which electrical energy can be generated and distributed and the precision and efficiency with which it can be applied and controlled.

Communication

Man's ability to communicate with other men far beyond the range of the spoken word represents a revolutionary step in his progress which has had cultural, social, and political consequences. In sequence came telegraph, telephone, wireless, radio, talking motion pictures, telephoto, and television. Amazingly, a brief span of about 30 years covers the time from the first home-built crystal sets to today's color telecasts viewed by millions. Whole new industries have been established, and the methods of warfare have been revolutionized through communications and the allied techniques of radar and sonar, navigational aids, and guided missiles. In addition the whole entertainment world has been reoriented to take advantage of the new media.

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* *Industrial* engineering has to do with the efficient use of manpower, machines, materials, and money in industry. It is considered by some authorities as a broad branch of engineering, by others as a subdivision of mechanical engineering, and by others as a specific engineering function. The last viewpoint has been adopted in this text (see page 93) because it permits relating industrial engineering more closely to the aptitudes and training required for work in this area.

Table 6. Distribution by Industry Field of 9,380 Electrical Engineers Surveyed in 1946*

Manufacturing		36.7%
Machinery, all kinds	26.5	
Transportation equipment	2.6	
Metals and products	1.6	
Chemicals and products	1.1	
Other manufacturing	4.9	
Communication		19.7
Utilities		16.7
Government		14.3
Construction		2.5
Transportation		1.5
Other industries		8.6
Total		100.0%

* Andrew Fraser, "The Engineering Profession in Transition," Engineers Joint Council, New York, 1946.

Communications engineering is firmly based upon scientific, quantitative principles. Advanced physical concepts and mathematical techniques are employed in all phases of the work of designing circuits, specifying tubes, and selecting values of circuit components. Because radio waves and electrical signals are intangible, the engineer must work from meter readings and other precision measurements.

The results of his wizardry become apparent when the flip of a selector switch brings a color television program into your living room. Three thousand miles away light energy reflected from the performers strikes a camera tube and is converted into a multitude of electrical impulses. Each impulse is characterized by position, color, and intensity. This information, after amplification, is superimposed upon a carrier wave and sent by cable to a relay station where it is converted to electromagnetic energy and radiated into space. At successive stations it is received, converted into electrical impulses, amplified, converted into electromagnetic energy, and reradiated. At the transmitting station it is broadcast in all directions as electromagnetic energy. With the touch of your finger, this one signal is selected from the myriad of signals from radio stations, police calls, navigation aids, and amateur transmitters along with radiations from diathermy machines, electric storms, and passing meteors.

Each little impulse is amplified, identified, and used to control a stream of electrons. These electrons strike fluorescent materials which give off light energy, thus forming a satisfactory picture.

Illumination

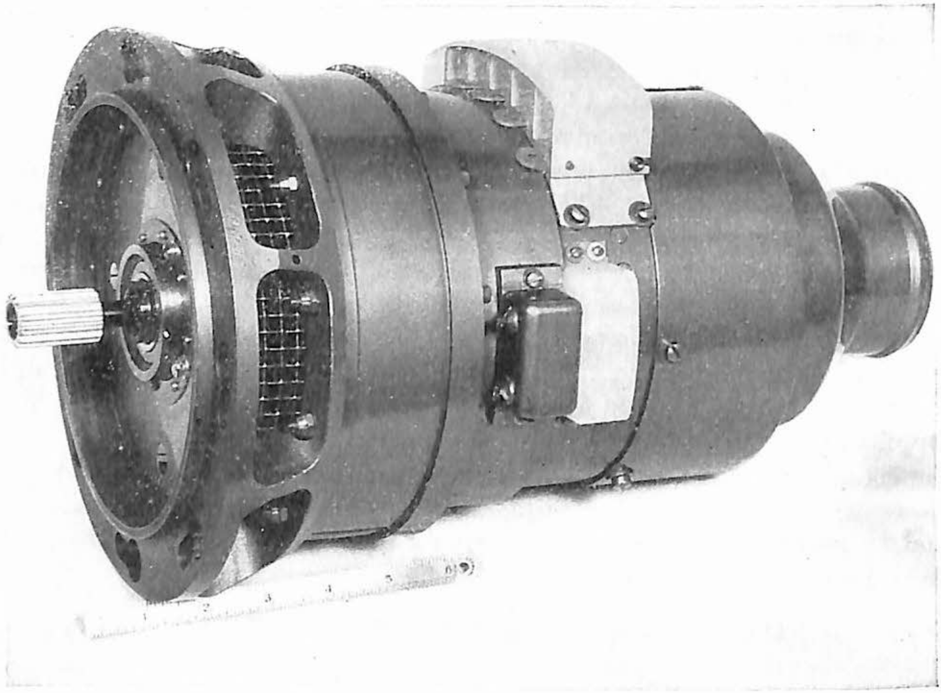
The universal appeal of an improved light source triggered the rapid development of the electric-power industry. The electric lamp itself has undergone spectacular improvements in efficiency and durability. Edison's original lamp gave about 1.7 lumens of light per watt of energy input. This was followed by the metallized carbon-filament lamp (4.25 lumens per watt), the tantalum-filament lamp (4.8 lumens per watt), the tungsten-filament lamp (7.85 lumens per watt), and the modern argon-filled lamp (9 lumens per watt). While the efficiency was being increased fivefold, the life has been increased by a factor of 50,000, and the present cost is but a fraction of that of early lamps.

In addition to hot filaments, electric arcs and fluorescent gases and solids serve as light sources. The light so produced includes infrared and ultraviolet energy outside the visible spectrum. Light is used in utility applications for lighting homes, schools, offices, factories, and highways; for signaling on land, at sea, and in the air; and for decorative purposes in store windows, advertising displays, theaters, and homes. The illuminating engineer works with light sources, reflectors, wiring, switches, relays, and photoelectric and other controls.

Power and Machinery

The capacity of electric generating stations in the United States exceeds 100 million hp. The generation, transmission, and distribution of this tremendous power are the responsibility of the electrical power engineer. He is concerned with locating hydroelectric, steam, and diesel engine power plants and specifying the engines, generators, and auxiliary equipment. In large stations the power is generated at around 20,000 volts and is stepped up by means of transformers to as high as 330,000 volts for efficient transmission over long distances. The efficient operation of individual power plants and the shifting of load between elements of large transmission networks are supervised by electrical engineers. Near the load center power is stepped down to lower voltages for safer distribution and easier control. The power is actually used at still lower voltages, usually 110 to 440 volts.

The end result of electrical energy is usually some other form of energy. Mechanical energy is supplied by efficient electric motors which are available in an almost endless variety of sizes, speeds, and operating characteristics. Thermal energy is obtained from easily controlled electric heaters and furnaces. Electrical energy may be stored in chemical form in batteries of electrolytic cells. Magnetic energy is available for lifting tons of scrap iron or operating sensitive galvanometers. Of the nearly 500 billion kilowatthours of electrical energy produced each year, the largest single block is supplied to motors. Assuming an industrial rate of 2 cents per kwhr, mechanical power costs us about 16 cents per hp-day or about 2 cents per manpower-day! It is no wonder that the electric motor has replaced the horse and the slave.



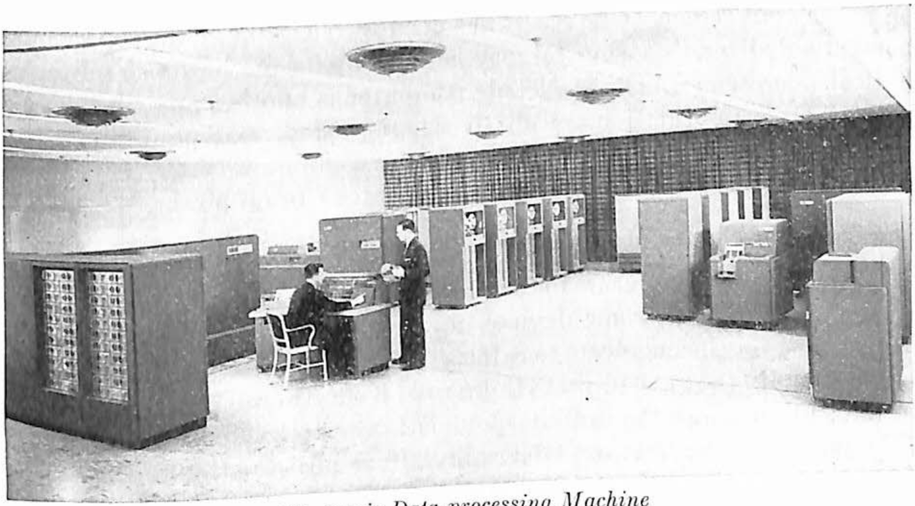
Electrical Engineering Progress

This new a-c aircraft generator was designed for high-speed, high-performance fighters. Every component has been designed for optimum performance with minimum weight. Castings are new creep-resistant magnesium alloy. By an ingenious use of a silicon rectifier the usual brushes are eliminated so that it can operate at high altitudes without difficulty. It is cooled by 300°F oil to permit higher output and operates at 8,000 rpm to permit weight reduction. Rated at 20 kva, 120/208 volts, it weighs only 44 pounds compared to 400 pounds for a standard industrial generator of equal rating. (*Westinghouse Electric Corporation.*)

Electronics

Electronics has to do with the conduction of electricity in gases and vacuo and in certain solid materials. Most of the properties of the vacuum tube were first developed and applied in the communications field, but electronics has now become much broader and includes industrial and special applications as well.

Communications. Vacuum tubes consisting of two or more electrodes in an evacuated space can be made to produce, detect, amplify, or rectify electrical oscillations (signals). Some of the functions can also be performed by gas-filled tubes and certain solid materials employed in transistors. Each has its particular field of application. Vacuum tubes vary from the miniature receiving types sensitive to micromicrowatts to powerful water-cooled transmitting tubes handling thousands of kilowatts.



Electronic Data-processing Machine

This "electronic brain" is capable of performing more than ten million operations an hour. A data-processing system is designed to meet a particular user's needs by selecting component units, each housed in a separate cabinet, which perform various functions. Essential components include the operator's control console, the arithmetical and logical unit which performs the operations, data storage units using magnetic tape recorders or magnetic drums, an input card reader whereby information on punched cards is fed into the machine, and an output printer or card punch which records the results in useful form. (*International Business Machines Corporation.*)

Industrial Electronics. Industry makes use of vacuum tubes in similar applications and also employs phototubes and gas-filled tubes. Vacuum-tube oscillators are used to supply electromagnetic energy for precisely controlled heat-treating of small parts. Amplifiers are used to sense and correct minute speed or voltage changes in powerful rotating machinery. Rectifiers convert large amounts of power from alternating to direct current for variable-speed motor drive. In larger current ratings, rectifiers are filled with gases such as mercury vapor to facilitate the flow of electrons between the electrodes and therefore increase the efficiency of conversion. Phototubes convert light energy into electrical signals, and this has resulted in an entire new field. Applications include counting, sizing, checking for defects, judging finish of rolled products, and even judging ripeness of fruit.

Special Applications. The precise control which can be exercised over the flow of electrons in a vacuum tube results in many special applications of the fundamental principles. The cyclotron is a giant vacuum tube in which charged particles are accelerated to tremendous energies while moving in a circular path in response to a magnetic field. Experience with the cathode-ray tube (picture tube) has led to the development of the field of electronoptics, the control of the paths of electrons to form images on fluorescent screens. One result has been the electron microscope which has extended man's vision far beyond the limits of the most powerful optical microscopes. The electronic computer is another amazing device which stores information, recalls it when needed, and performs in an instant mathematical calculations which would take years of mental effort. It conserves our most valuable resource—brain power.

The Future of Electrical Engineering

It would take many years for engineers to exploit fully the potentialities of electrical and electronic devices now available. But the scientists are not waiting for the engineers to catch up. A conservative prediction would be that within the next 10 years there will be more new developments than in the 60 years since the first development of water power at Niagara and Marconi's work in wireless telegraphy. Here is a great opportunity for those with youth, aptitude, and ambition.

CHEMICAL ENGINEERING

Chemistry has to do with the composition and changes in composition of substances and with the preparation, separation, and analysis of substances. Chemical engineering is concerned with the manufacture on an industrial scale of substances from raw materials through controlled chemical and physical changes. Chemical engineering is closely allied with, and there is considerable overlapping with, ceramic, petroleum, and metallurgical engineering branches and electrochemical and combustion sub-branches. In this discussion the emphasis will be on the work of those who call themselves chemical engineers. The nature of this work will be indicated by pointing out the industries where chemical engineers find employment and by discussing the processes whereby substances are manufactured efficiently and economically.

Industries Employing Chemical Engineers

While chemical engineers are useful in a great variety of enterprises, the great majority are employed in four manufacturing industries: chemicals, petroleum, rubber, and foods (see Table 7). The work consists of developing new products, designing new and improved processes, and operating plants efficiently.

TABLE 7. DISTRIBUTION BY INDUSTRY OF 3,648 CHEMICAL ENGINEERS SURVEYED IN 1946*

Manufacturing		82.3%
Chemicals and allied products (including synthetic fibers)	45.2	
Petroleum and coal products	16.9	
Rubber products	4.2	
Food and kindred products	4.0	
Iron and steel and their products	2.9	
Machinery	2.8	
Paper and allied products	1.7	
Stone, clay, and glass products	1.0	
Other manufacturing	3.6	
Education and personal services		6.9
Other industries		10.8
Total		100.0%

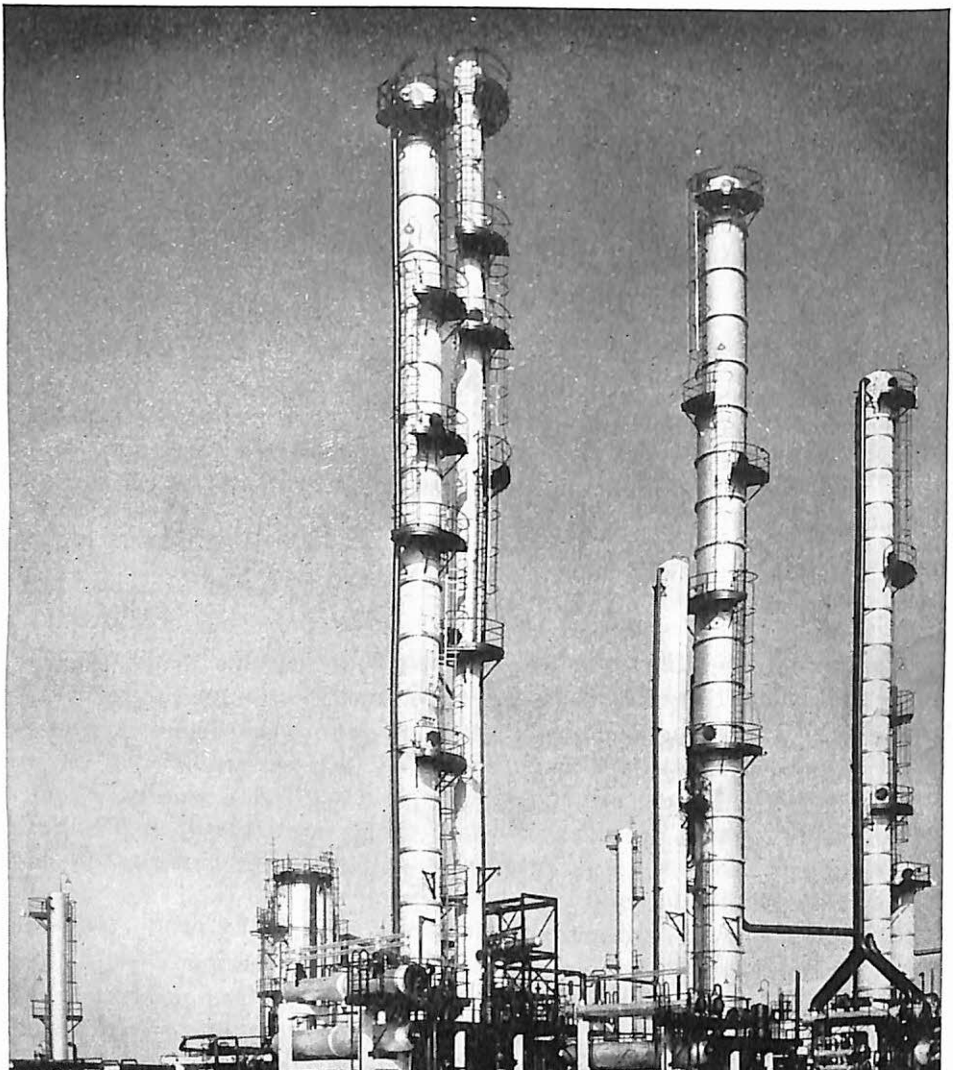
* Andrew Fraser, "The Engineering Profession in Transition," Engineers Joint Council, New York, 1946.

Chemicals. The "heavy chemicals" include various acids, alkalies, salts, and other chemicals used in great quantities in manufacturing and processing. The "fine chemicals" include pharmaceuticals, cosmetics, insecticides, and photographic materials. The plastics are of great importance now because they are cheap, light, easily molded, and chemically resistant. Rayon and the newer synthetic fibers available since 1940 have revolutionized the clothing industry with materials which are softer than silk, warmer than wool, and as inexpensive as cotton.

Petroleum. Some of these fibers are produced from by-products of the petroleum industry. In fact petroleum is now recognized as a versatile raw material for manufacturing a great variety of important products—the petrochemicals. The fuels, lubricants, and solvents made from petroleum have established themselves as essential parts of our civilian and military operations.

Rubber. The rapid adoption of the pneumatic-tired automobile made the United States the world's largest consumer of rubber products. Rubber is made from the gum of a tropical tree, and its natural supply is limited. World War II stimulated the demand for a synthetic rubber, and its development marks a milestone in chemical history because it involves changing the molecular structure to create entirely new substances.

Foods. Many of the activities of the engineer are aimed indirectly at improving the world's food supply in quantity, quality, and cost. The chemical engineer works directly in producing and processing food products. As a result of his work the previously discarded cotton seeds are



Separation and Fractionation Units for Manufacture of Phenol and Acetone

Phenol is an important industrial chemical used in the manufacture of resinous binders for laminated wood and glass-wool insulation. Customarily, phenol is produced from benzene using chemicals which are in short supply. The plant pictured was the first to synthesize phenol from purely petroleum sources and has a design capacity of 35 million pounds of phenol and 20 million pounds of acetone a year. Development of the processes on a commercial basis, design of the units and utilities, and construction of the plant required two years of intense engineering activity. (*Standard Oil Co. of California.*)

turned into fertilizer, animal feed, and valuable vegetable oil. Corn now yields a long list of valuable materials including dextrose, glucose, corn sirup, and corn oil. Hydrogenation of vegetable oils transforms them into fats which may be used in place of the more expensive butterfat and animal fat. The chemical engineer's greatest contribution is in adapting test-tube reactions to mass production so that the research chemist's work results in benefits to all.

Unit Operations

The manufacturing processes employed are made up of combinations of a relatively few basic chemical and physical processes called unit operations. These can be grouped into four general classifications.

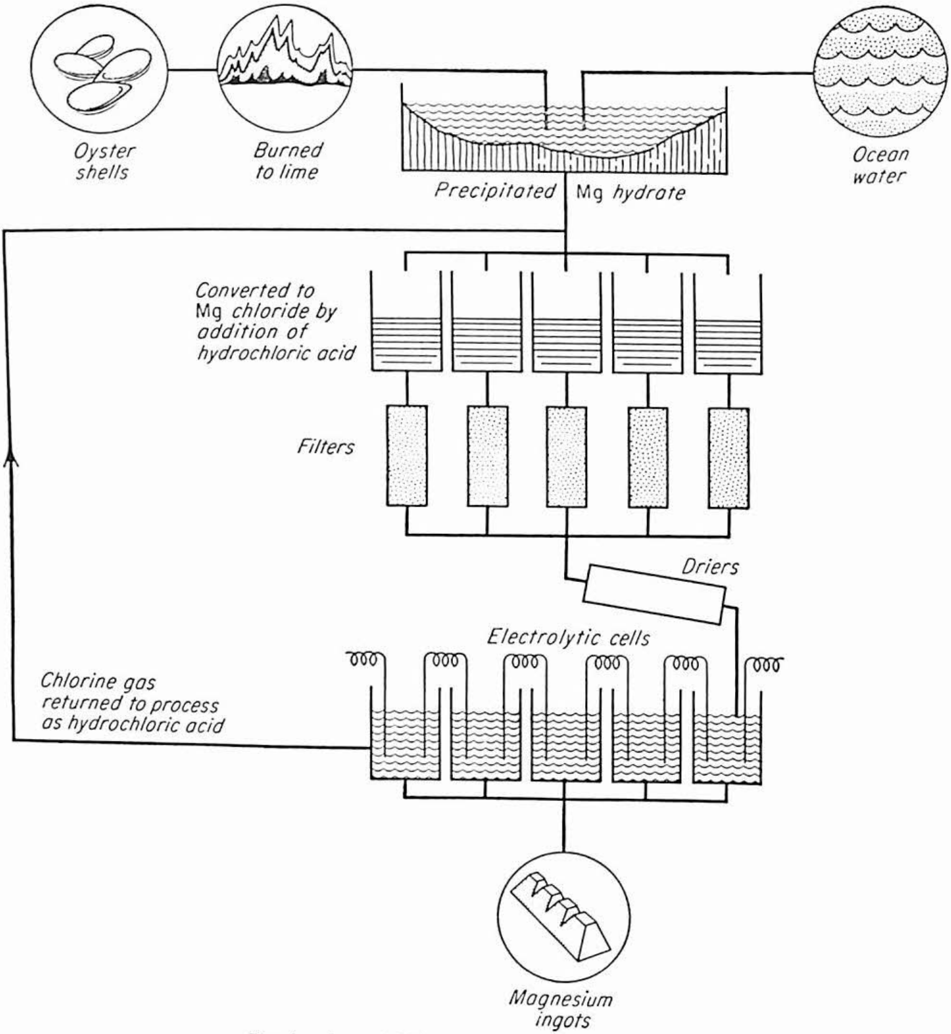
Mechanical Action. This category includes materials handling, fluid pumping, mixing, shredding, crushing, grinding, sizing, filtering, and settling. The equipment which performs these operations is usually cleverly contrived to produce the desired result, is power driven for quantity output, and includes a variety of manual and automatic controls.

Physical Separation. Over and over again the chemical engineer faces the problem of separating the desired product from the undesired. This is done by evaporation, absorption, adsorption, distillation, fractionation, and precipitation. The first operation of these processes in the research laboratory may be carried out in glass units, while the production plant may tower a hundred feet in the air and represent a million-dollar investment.

Chemical Reaction. In many processes a chemical change must be produced as in smelting ore or making soap. Other so-called unit processes involve oxidation, reduction, hydrogenation, chlorination, polymerization, etc. These reactions are carried on in tanks, furnaces, retorts, towers, and other units especially engineered to produce the desired result at a minimum cost.

Heat Transfer. Frequently the output of a given plant may be increased by carrying on the reaction at high temperature. Some desired reactions will take place only within narrow temperature limits, and cooling may be necessary. Heat transfer involves conduction, convection, and radiation. The chemical engineer works with heat exchangers, furnaces, evaporators, condensers, cooling towers, and refrigeration units.

In setting up the manufacturing plant, the chemical engineer selects the individual processes and arranges them in the proper sequence. Of great importance are the process controls and instrumentation which enable the engineer to accomplish the desired result and keep track of the performance of each unit. In any commercial installation piping presents many problems, and there are always structural problems.


Oyster shells
Burned to lime
Ocean water
Precipitated Mg hydrate
Converted to Mg chloride by addition of hydrochloric acid
Filters
Driers
Electrolytic cells
Chlorine gas returned to process as hydrochloric acid
Magnesium ingots

Production of Magnesium from Sea Water

The diversity of means employed by the chemical engineer in his "conversion of natural resources to the benefit of man" is illustrated by this process whereby the sea is made to yield some of its treasure. What different unit operations are represented in the diagram? What engineering sub-branches are represented? (*Dow Chemical Co.*)

The Future of Chemical Engineering

As the youngest of the major branches of engineering, chemical engineering possesses a tremendous growth potential. Probably there has been more industrial research in this field than in any other. One major company in this field has pointed out that nearly half of its 1942 gross sales were of products which were either unknown or not commercially produced as late as 1928. The American chemical industry was established as a result of World War I and greatly stimulated by World War II. It is sure to continue to grow under the stimulus of the never-ending war for better health and a higher standard of living.

OTHER ENGINEERING BRANCHES

Wherever a special field develops specialized knowledge and techniques, progress demands engineers who concentrate their efforts in that limited area. Some of these are readily assigned as sub-branches of the five major classifications. Others cross over several categories or involve unusual characteristics which make them unique.

Agricultural engineering* involves the application of engineering principles and techniques to the agricultural industry. It includes the following divisions: power and machinery, structures, soil and water conservation, electrification, and processing of farm products.

Acoustical engineering involves the application of engineering principles and techniques to sound production, amplification, recording, reproduction, detection, and control. It includes the following divisions: architectural design, noise control, sound recording and reproduction, and sound ranging (sonar).

Geological engineering* involves the study of rocks and soils to determine the structure of the surface and subsurface. The geological engineer obtains information from soil analyses, excavations, valley walls, wells, aerial photographs, and geophysical measurements using gravitational, electric, magnetic, and seismic instruments.

Naval Architecture* involves the design of floating structures such as ships, barges, tugs, dredges, submarines, and buoys for commercial, naval, pleasure, and navigational purposes.

Marine engineering* involves the application of engineering principles and techniques to propulsion machinery for driving vessels, power supplies for shipboard service, navigation control systems, and communication systems. Included are many mechanical, electrical, and electronic units.

Military engineering involves the application of engineering principles and techniques to military situations. Military engineering places time above cost and meeting the need above refinement of design. Military engineering includes roads, shelter, fortifications, water supply, transport, and communications.

Ordnance and armament engineering* involves the material used in waging war on land, sea, and air, including weapons, ammunition, fire control, and tank vehicles, and the equipment and plants used in manufacture, testing, transporting, and storing ordnance material.

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* ASME *op. cit.*

Nuclear engineering* involves the design and operation of equipment and systems in which nuclear fission is carried on at a controlled rate for the production of fissionable or radioactive material or the generation of useful energy. The nuclear engineer is concerned with the chemistry and metallurgy of unusual materials, protection of personnel from dangerous radiation, instrumentation of complex processes, remote control of hazardous operations, and operating equipment at extremes of temperature and pressure.

SUMMARY

The engineering field is broad and diverse. It is concerned with modifying molecules at one extreme and working with tremendous masses of concrete at the other; it embraces destruction and creation; it includes use of minute quantities of electromagnetic energy plucked from the atmosphere as well as attempts at harnessing the vast energy of the sun. There is a branch of engineering to match any interest. However, all the specialized engineering subdivisions are unified in method and objective—"applying science to the efficient conversion of natural resources to the benefit of man."

ASSIGNMENTS

5-1. From the current periodicals in your school or public library, obtain information about a recent engineering project or achievement and answer the following questions:

What is the general nature of the project?

In what ways does this represent an advance or an innovation?

What branches of engineering are represented by the engineers engaged in this work?

5-2. Select a branch of engineering which interests you, and interview an engineer engaged in that work. Discuss with him the future of his branch of engineering. In a brief report, indicate his name and position and list five new developments to be expected or problems to be solved in the near future.

5-3. In many respects the growth of the engineering profession resembles the growth of a tree. With its roots in the basic sciences and practical arts drawing on the natural resources of the earth, the tree of engineering has developed from a sapling to a productive, but still rapidly growing, stage with a sturdy trunk, primary branches, and a host of twigs. Sketch on 8½- by 11-in. paper the tree of engineering appropriately labeled.

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* *Ibid.*

6

FUNCTIONS OF ENGINEERING

From the preceding chapter it should be apparent that engineering covers a tremendous range of topics. Which of those discussed were particularly interesting to you? Is that interest strong enough to form a foundation for building a career?

It was pointed out earlier that the fields of engineering indicate what the engineer works *with*. For example, when you hear the words "civil engineer," you probably think of bridges, buildings, highways, etc. "Electronic engineer" immediately produces a mental image of vacuum tubes and circuits. But in your mental picture, what is the engineer *doing?* What would you be doing if your career led in one of these directions? The devices, products, and structures which have been described are the *results* of engineering. Engineering itself is essentially a mental activity; you very seldom see engineering. To complete your picture of engineering you need to know what engineers do. This can be described best in terms of functions.

Another reason for emphasizing the functional classification is that while fields are usually related to the engineer's interests, the functions tie in more closely with his aptitudes. A certain type of individual is needed for research, whether it is in the field of chemistry or electronics. Also, the training required to design a bridge is basically the same as that necessary to design an aircraft fuselage or the housing for a large electric generator. Usually an application engineer must be prepared to make recommendations from his company's entire line of products, whether they be electrical, mechanical, or chemical in nature.

Listed in order of decreasing scientific emphasis, the major engineering functions are research, development, design, construction, production, operation and maintenance, application and sales, industrial, and management. This is a finer classification than occurs in industry. Research and development are frequently combined in a single department, and in some organizations the same persons perform design and construction. Sometimes industrial engineering activities are broadened to include production and management functions as well. The more precise definitions are used here to bring out, to you as a beginning student, the small differences in duties and requirements.

To provide an understanding of what engineers do, each major function is defined briefly and then discussed in detail with illustrative examples. To help you in your selection of a career, the personal qualifications for work in each function are listed and the most desirable type of training is indicated. Emphasis is placed on the concept of engineering as a broad spectrum of activities offering a variety of careers rather than a single, narrowly defined activity.

RESEARCH

Research has been described as "a blind man in a darkened room looking for a black cat that probably isn't there." This statement highlights two important aspects of research work. Since the research scientist or engineer is working on the frontier of knowledge, he is "in the dark" and on unfamiliar ground, usually with inadequate tools and techniques. Second, he must expect many failures before he attains each success. In some cases his success may be of a negative kind; many months of work may be required to prove that a certain theory is not true or that a certain method will not work.

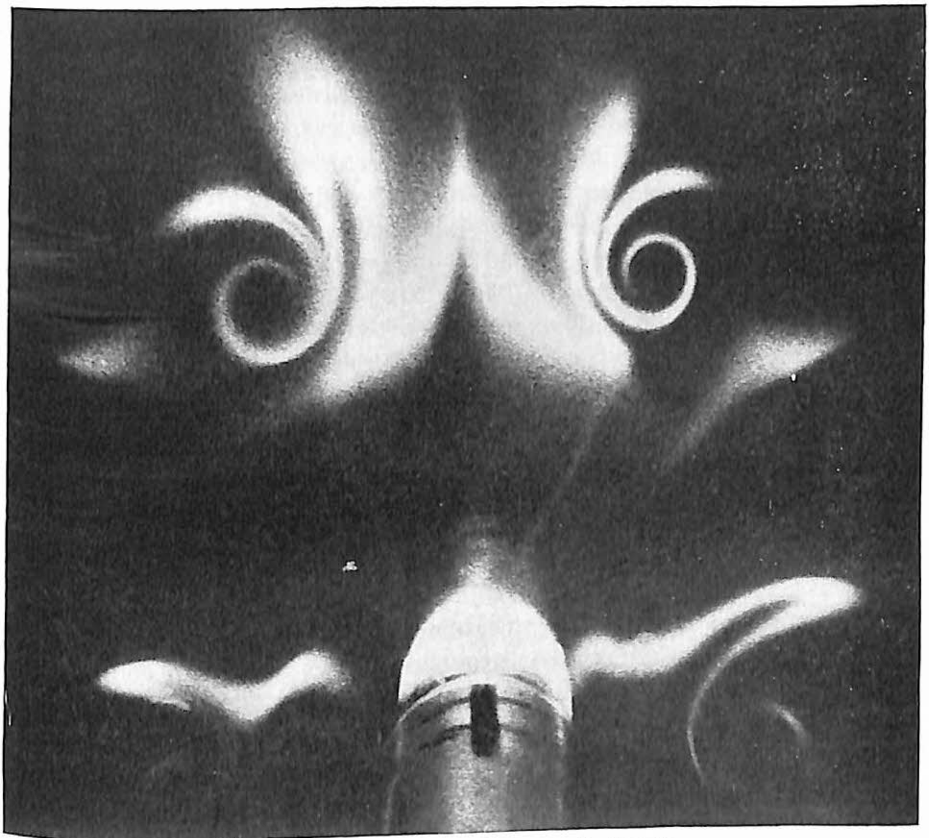
Relationship of Engineer to Scientist

There is a close relationship between the research engineer and the research scientist. One distinguishing characteristic is that the aim of the scientist is to know—to discover truth for its own sake—while the engineer, by our definition, has in mind a definite use for the new information. For example, a physicist may be interested in discovering the fundamental facts behind the propagation of a flame in combustible gases; an engineer in the same field concentrates his attention on what happens under the conditions which could occur within the cylinder of an automobile engine. A chemist may make his contribution by carefully measuring a particular property of a long series of compounds; in seeking to find the one compound which exhibits that property to the greatest degree, the research chemical engineer has in mind how that property could be exploited. Sometimes the distinction is made by calling one "pure" and the other "applied" research.

Examples of Research Problems

As you read this, thousands of American scientists and engineers are engaged in the mental activity called research. To illustrate the work they are doing, let us consider some typical research problems.

Aerodynamics. What determines the distribution of pressure and velocity over an airfoil section at supersonic speed? How are these factors affected by temperature, density, and viscosity of the air; by roughness, temperature, and angle of the airfoil? Most research work is directed



Vortexes Generated at Supersonic Speeds

In research on vortex interference and its effects on airplane stability, the vapor-screen technique permits visualizing the flow field at supersonic speeds. The cross-shaped wing model (not visible) is supported by the sting mount shown at the lower center. Fog is introduced into the wind tunnel and a thin plane of the fog is illuminated. A camera records the vortex patterns developed downstream from the model at various Mach numbers and angles of attack. This picture was taken at Mach 1.4 (1.4 times the speed of sound). The cruciform (cross-shaped) wing is considered suitable for guided missiles. (*Ames Aeronautical Laboratory, N.A.C.A.*)

toward answering questions of this type through the use of advanced tools and techniques. In the field of aerodynamics, tools include wind tunnels which will accommodate model or full-scale aircraft, apparatus for observing flow patterns and shock waves, and multiple manometers for simultaneous pressure readings. Another powerful tool is mathematics, by means of which it is possible to express fundamental physical relations and to reduce masses of data to precise conclusions. Using mathematical principles it is possible to determine from tests on small models just how full-scale planes will perform.

One standard technique in engineering work is the experimental method wherein all except one factor or condition are held constant. Using this approach it has been discovered that many performance characteristics are determined by the ratio of the speed of the aircraft to that of sound. This ratio is called the Mach number after Ernest Mach, an Austrian physicist who did original research on shock waves. One important area of aerodynamic research is concerned with theoretical and experimental evaluation of performance in the *transonic* region near Mach 1.0—the speed of sound. Research engineers are also working in the *hypersonic* region to exploit the potential advantages of intercontinental missiles traveling 10,000 to 15,000 mph (Mach 20).

Chemical Engineering. What characteristics of the molecule determine its mechanical properties? What is the nature of the bonds joining molecules in stable compounds? What peculiar characteristic of rubber permits it to be stretched elastically several times its length? How can that characteristic be incorporated into synthetic rubber? How do plants manufacture oxygen? How can oxygen be manufactured cheaply from air? These questions are typical of those asked by the research engineer in the chemical field.

It was pointed out previously that the value of research in industrial chemistry was recognized earlier than in other engineering fields. This was probably owing to the fact that progress in other fields had come about over a long period of time through trial and error. Chemical engineering sprang up almost overnight, and mathematical tools, engineering sciences, and experimental methods were available to make it possible for imaginative men to seek out new knowledge and new products instead of waiting for their chance development.

Research Engineering

Research is now Big Business. Back in 1920 there were a hundred or so industrial research laboratories working on a total budget of less than 1 million dollars per year. Today there are probably 10,000 industrially sponsored laboratories with an annual expenditure of over 2 *billion* dollars. Research is being carried on in four major types of institutions: colleges and universities, industrial laboratories, organizations sponsored by the Federal government, and research institutes. As an aftermath of World War II the government has greatly expanded its emphasis on research and development, and more than half of all scientific research is government supported.

In most cases a team of engineers and/or scientists is set up to tackle a given problem. Depending on the nature of the problem, the team will include experts in heat transfer, metallurgy, fluid flow, electronics, chemistry, or mathematics. Some men will be strong in basic theory; others, skillful experimenters. In most cases they will require specialized equipment and apparatus and the assistance of skilled craftsmen. While important contributions will still be made by individuals, the day of the hungry inventor working away in his cold garret is nearly over.

The actual research work is essentially mental, and results are usually in the form of ideas. These ideas may be expressed in the form of a new law expressing the relationship between physical factors, a graph presenting data on performance of a new process, observations on a newly discovered phenomenon, an explanation of a previously observed phenomenon, proof of the accuracy of a proposed theory, or proof of the inadequacy of a theory. To be of value, the results must be communicated to the ultimate user. This may be done in a brief memorandum, a talk before a technical society, or a formal report to the sponsor.

Requirements for Research Work

Success in research usually requires a particular set of aptitudes developed by thorough training.

Personal Qualifications. What are the particular personal qualifications required for success in research? Since research requires doing what no one else has done, a high intellectual ability is usually necessary. Because it is work in an unknown field, imagination and intense curiosity are desirable. Patience and self-confidence will prevent discouragement over the many failures. Open-mindedness and intellectual honesty are important in any scientific work because without them the researcher may permit his preconceived ideas or personal bias to obscure the truth. Ability to cooperate with others in a team effort is of extreme importance as well as ability to express oneself to his coworkers, his assistants, and his superiors.

Training. What type of training is desirable? The research engineer must have a broad training in fundamental engineering sciences, and at the same time he needs the advanced specialized training which makes him valuable. In general this combination is provided by a basic 4-year engineering program followed by graduate work in a specialty. The basic course should include strong mathematics preparation and emphasis on engineering science rather than present engineering practice. The graduate work should include advanced scientific concepts and an introduction to research work. The number of engineers completing the master's degree (1 year) and the doctor's degree (3 years) is steadily increasing. The advanced degrees culminating approximately 7 years of intensive study are particularly valuable in research.

DEVELOPMENT

From the research laboratories of the world there pours a continual stream of new knowledge. These new principles, processes, and products constitute the raw material for the development engineer. His job is to apply them to useful purposes. A new concept of flame propagation suggests an improved cylinder-head design. Knowledge of molecular structure points the way to a method of producing synthetic rubber. Data on supersonic air flow indicate how more lift may be obtained in high-speed aircraft. The transistor suggests the possibility of a miniature hearing aid. For the same reason when an engineer is given the job of developing a new or better or cheaper device or process, he turns first to the literature to see what has been accomplished by researchers in that field.

The development engineer occupies a position between research and design. His result is usually in the form of a working model which is then designed for economic production. A given individual may perform research, carry on development, and also participate in design. This is especially true in a small company. However, the three functions are quite distinct.

Development Engineering

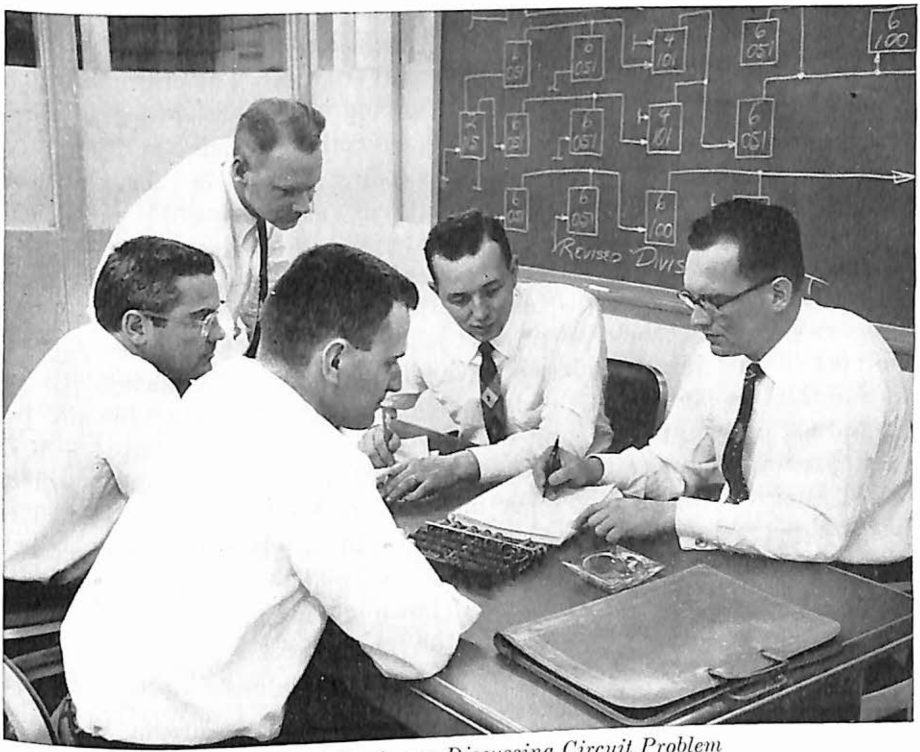
The work of the development engineer will be illustrated by an example from the electronics field because a large proportion of electronic engineers are engaged in this function. Suppose that the U.S. Signal Corps needs a portable test unit for field work. A set of specifications is drawn up, a contract signed with the development company, and then the project is turned over to a development engineer.

The engineer carefully reviews the specifications stipulating electrical, mechanical, and thermal characteristics. From his experience he identifies the probable "bottlenecks," the limitations which are going to be difficult to meet. These might be extreme lightness, unusually low distortion, or wide range of operating temperature. It is the combination of such specifications which demands a new unit.

His next step is to review the literature to see how others have solved similar problems or how new research has pointed the way to possible solutions. He may have to translate, or have translated, articles by German or French or Japanese experimenters. In a large organization the library staff works continuously at reading and summarizing articles of interest.

The next stage in development will be mental—attempting to create in the mind a new device with the desired characteristics. The emphasis here is on the "bottlenecks"; the engineer pays little attention to those portions of the circuit where a standard approach will suffice. He may lay out a circuit in block form just indicating the functions to be performed. The new elements must be designed, and values calculated and specified.

A "breadboard" model may be constructed next. This is a flexible unit which is spread out to permit changing circuit elements and repositioning units. Usually the electronics engineer constructs his own models, but in other fields a technician or a crew of skilled artisans will do the construction. This is not trial and error but rather a series of rational steps in which each change is based on measurement and observation. Standard signal generators, sensitive oscilloscopes, precise instruments, and calibrated circuit elements provide the necessary data.



Development Engineers Discussing Circuit Problem

The development engineer occupies a position between research and design. His raw material is the stream of new knowledge contributed by research engineers, physicists, chemists, and other scientists. His responsibility is the application of new information to the creation of devices, or processes, or products. His results are frequently in the form of working models which are then designed for economic production. The engineers in the photograph are discussing a preliminary model of an electronic data-processing machine using the pluggable unit shown. (*International Business Machines Corporation.*)

On the basis of results with the "breadboard" model, a development model will be designed. This unit is constructed to meet mechanical specifications and tested to see that it complies with electrical and thermal requirements. It may include components which were especially built for that job. Ordinarily this preliminary model involves much handwork. When it is constructed, tested, and accepted by the sponsor, development is completed.

Invention

In the present organization of engineering, the inventor probably falls in the same classification as the development engineer. The original meaning of invent was "to come upon"—implying by chance. Many of Edison's inventions were the result of trying everything which could possibly produce the desired end. This method is still important in those fields of engineering which cannot be treated mathematically.

One field in which invention is important is in the development of fruit-processing equipment. In the past, fruits have had to be processed individually and by hand because of the variation in size and ripeness and the presence of imperfections. As a result labor costs have been a big part of the cost of the final product, and that is the type of situation where mechanization can be justified. Included in this category would be harvesters, peelers, pitters, and sizers.

Suppose an engineer was given the job of devising a machine which would separate 16,000 olives per minute into 10 different sizes with a specified percentage error. First he might make a patent search to check on all different methods of sizing. Most methods are based on diameter, with the smallest separated out first. That might be a good reason to consider methods which would take out the largest first.

Here again the second stage would be mental, endeavoring to visualize various devices which would accomplish the desired result. He could imagine photocells replacing human eyes and mechanical feelers substituting for human fingers. Laying out possible arrangements on paper would bring into focus other problems such as power supply, feeding mechanisms, and mechanical supports.

The preliminary model would be bulky but flexible. It would probably include some components originally designed for other uses and other parts laboriously made by hand. Operation of the model would reveal its shortcomings as well as its virtues. Perhaps several successive models would have to be built, each incorporating the improvements necessary to overcome the inadequacies of the previous model. This type of development engineering requires a strong background in engineering science, but there is less emphasis on mathematical calculation.

Requirements for Development Work

There are small but significant differences between the work of the development engineer and that of the research engineer, and those differences are reflected in the qualifications desired.

Personal Qualifications. It should be obvious that a successful development engineer must be ingenious and imaginative. His job is to create, and creativity is a highly salable commodity. He should be skillful in experimentation, able to make accurate observations and draw correct conclusions. In most organizations, development is a group effort, and one must be able to cooperate with others, making his contribution without worrying about getting credit for it.

While ability to express oneself is important in all engineering functions, the ability to "sell" one's ideas is particularly important in development. The cost of conducting a development program may run into many thousands of dollars and involve shop facilities and men in addition to the engineers. Management must be convinced of the value of the idea and of the ability of the one who proposes to develop it.

Training. The technical training required for development varies with the field. In the more scientific fields such as electronics, aeronautics, and heat transfer, the broad training in engineering science of the bachelor's degree should be supplemented by specialized training on the graduate level. Employers recognize the value of advanced work in development by paying higher salaries to men holding master's and doctor's degrees. In the field of "invention," mechanical skill and practical experience in the field may be more important than academic training. In any event the development engineer is always working in a new area, and he needs all the tools, techniques, and knowledge at his command.

DESIGN

In engineering work the word "design" is used in two different ways. In general, design means to "create in the mind"; starting with a definite purpose, various elements are imagined to be combined so as to accomplish that purpose. In this sense a report is "designed" to persuade a certain type of reader toward a desired action. A manufacturing organization is designed to fabricate a product for a given market. A qualified designer is able to predict how well his design will perform and what it will cost.

More specifically, design as an engineering function lies intermediate between development and production or construction. It is the responsibility of the design engineer to take the working model from the development engineer and prepare it for economic production in a factory if there are to be many or construction on the site if there is to be but one.

Design for Production

A thorough knowledge of the properties of materials and the capabilities and limitations of fabrication processes is an essential part of the designer's training. Frequently a development model will contain elements which would not be suitable for mass production. The design engineer will replace handmade elements with standard, and therefore inexpensive, items. Fasteners such as bolts and screws are mass-produced in standard sizes, and seldom is a special item justifiable. In the model a part might be made of platinum to prevent corrosion, but in the production unit either the cause of the corrosion should be eliminated by proper design or a less expensive stainless steel might be employed. As he prepares his plan the design engineer must have in mind how die-cast parts might be used instead of individually machined items and how a single operation on a hydraulic press might replace several welding operations.

Another important contribution by the design engineer is based on his knowledge of the behavior of materials under the action of static and dynamic forces, electrical currents and voltages, and thermal stresses. Any factory laborer can select a timber beam large enough to pry up one end of a machine tool. If his first solution to the problem is too small and the beam breaks, he merely selects a larger one. The design of a structural member of a 4-million-dollar airplane which will carry 100 passengers at a speed of 500 mph 20,000 ft above the earth is a different matter. Aircraft design has been refined to an extreme degree because of the need for safety on one hand and light weight on the other. Every ounce of structural material must be working at its maximum capacity, and to achieve this condition the design engineer must take advantage of every pertinent scientific advance.

Similarly the electrical designer must specify just that amount of copper which will carry the current without the excessive heat which would shorten the life of the motor, for example. In specifying the insulation to be placed around a steam pipe, the mechanical designer must calculate the cost of each additional inch of thickness and compare that cost with the corresponding saving in operating. As Wellington pointed out in his definition, the design engineer must do the job "well with one dollar . . . ."

In addition to working with the fabrication and performance of materials, the design engineer is concerned with methods of accomplishing such things as complex motion, heat transfer, lubrication, speed control, and provision for safety. In some cases the desired result may be achieved mechanically, electrically, hydraulically, pneumatically, or electronically. The fact that there may be many solutions to the same problem usually comes as a shock to the recent engineering graduate, accustomed as he is to problems with only a single solution. After preliminary consideration the designer must decide on a single method and proceed. Making that decision is usually difficult for the inexperienced designer.

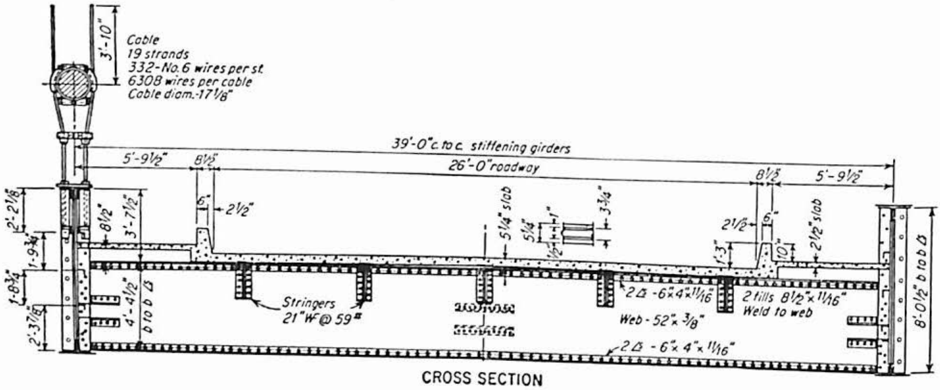
In general the best design is the simplest. To paraphrase Wellington: "Anyone can plan a complicated machine; it takes an engineer to design a simple one." Another characteristic of good design is that it is balanced. There is no point in providing a 10-hp motor to drive a device which never requires that amount of power, nor should one part of a device be of such great strength as to far outlast the other elements. The modern automobile is a good example of balanced design. About the time the tires wear out, in normal use, the battery is on its way, the brakes need relining, a valve job is nearly due, and seat covers are required. For an extreme example of balanced design reread "The One Hoss Shay" by Oliver Wendell Holmes.

In designing consumer goods the factors of appearance and style are becoming increasingly important. It isn't enough that an electric toaster lightly browns slices of bread; in addition it must look well on the owner's kitchen table and impress the viewer with the owner's good taste. As well as being "streamlined," an automobile must give the appearance of going 90 mph even while standing at the curb. Improper use of this design approach has resulted in streamlined washing machines, refrigerators, and other items equally unlikely to take flight. The best engineering design in which each component serves a definite function is usually aesthetically satisfying. The supersonic airplane and the suspension bridge are good examples.

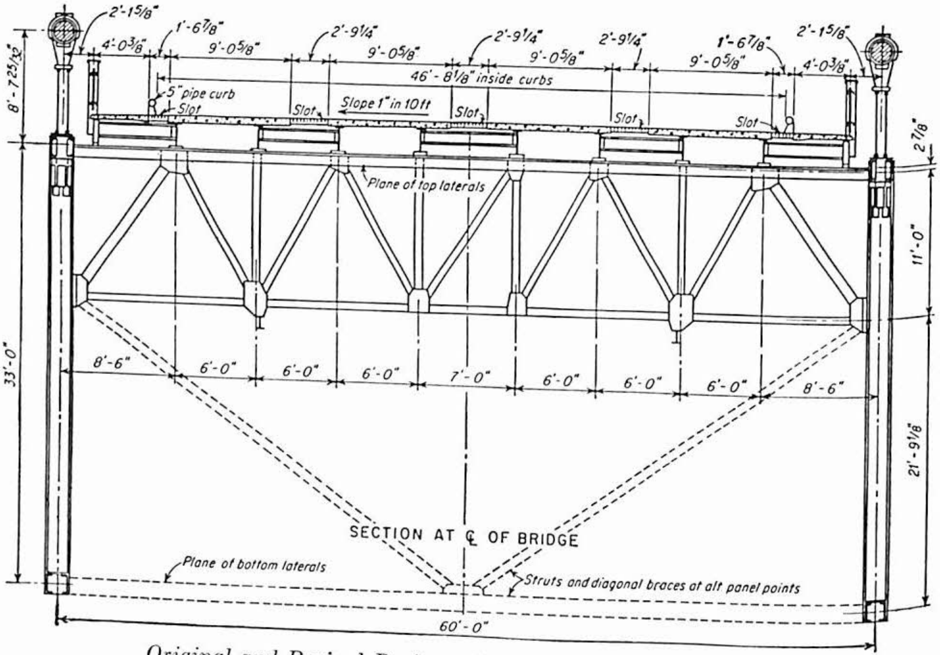
Design for Construction

Many of the foregoing remarks are directly applicable to the design of structures. The structural designer must know the properties of steel, concrete, timber, aluminum, masonry, etc. While he is concerned primarily with static loads, impact and other dynamic forces must be taken into account in providing for such factors as resistance to earthquakes. The number of structural elements is relatively smaller and includes beams, slabs, girders, columns, trusses, arches, continuous frames, and diaphragms. Each of these has its particular application in creating a structure.

Certain aspects differentiate the design of a bridge, say, from that of an automobile. The structural engineer must have a great deal of information about the site—topographical information, soil and geological data, information on stream flow, etc. Since only one bridge is to be built, usually there is no opportunity to modify the design and correct original errors. A unique exception was the 6-million-dollar Tacoma Narrows Bridge which failed soon after its completion in 1940. This slender suspension bridge (2,800-ft main span) showed tendencies to oscillate up and down even during construction and was nicknamed "Galloping Gertie." On Nov. 7,



CROSS SECTION



Original and Revised Designs of the Tacoma Narrows Bridge

The original design was for a lightweight, flexible, two-lane structure with 8-foot plate-girder stiffeners along the sides. Wind-tunnel studies of a model showed that the solid roadway and flexible construction made it susceptible to violent oscillations under proper wind conditions. The new design came after consultation with aerodynamicist Theodore von Kármán, mathematical analysis, and careful wind-tunnel research. In the new design, 33-foot trussed stiffeners, open-truss floor beams, and a slotted roadway of lightweight concrete were specified. These provisions should provide stability in winds up to 120 mph, the design criterion. (*Washington State Toll Bridge Authority.*)

1940, the oscillation began to build up under a moderate wind and then abruptly changed into a writhing motion. Within an hour the violent twisting had torn the bridge to pieces. Ten years later, after much study, experimentation, and wind-tunnel research, a new bridge of satisfactory design was constructed on the same site.

Requirements for Design Work

From this description of the duties of the design engineer we can draw some conclusions regarding his personal qualifications, training, and experience.

Personal Qualifications. He must be creative because he is called upon only for new designs. He must be able to visualize mechanisms and structures which do not exist. He must be able to think on paper; the ideas for which he is paid become useful only when they are expressed in drawings and specifications. He must be able to decide which of alternate solutions is preferable and go ahead on that basis. He must be cooperative, since important designs are usually group efforts. He must remain open-minded and avoid becoming attached to an idea just because it is his own.

Training. While engineering design is not a closed profession, the 4-year college training is almost essential. The training must be broad because major design projects include a variety of engineering problems. A strong background in engineering economy is desirable; a design must be economical in terms of materials, fabrication, installation, operation, and maintenance. In addition consideration must be given to aesthetic factors, and frequently the physiological limitations of the user guide the design. A knowledge of law will facilitate understanding contracts and checking on patents.

Experience. Desirable experience for a graduate aiming toward a career in design would provide two things. In the first place, the designer must have a background knowledge of production and/or construction methods. This can be obtained by actual experience as a construction inspector or by working in a shop or on production test. Second, he needs skill in presenting ideas graphically. A starting position as detailer will enable him to learn company practice and develop his skill. After this he may be given responsibility for making minor modifications of old machines. As soon as he demonstrates his ability in this work, he is on his way to becoming a design engineer.

CONSTRUCTION

The construction industry constitutes a large segment of the national economy and employs nearly one-fifth of all engineers. Within the industry are found engineers performing each of the nine major functions. In this discussion, however, the term "construction engineering" will be used to mean the work of building structures which have been designed previously and will be operated subsequently.

The construction engineer receives from the design engineer a set of plans and specifications. These vary in complexity from a single sheet with sketches and notes to a set with hundreds of drawings and thousands of pages of specifications. It is the job of the construction engineer to turn the visions of the designer into reality—to translate pencil lines into steel and concrete.

The majority of construction engineers are engaged in heavy construction—buildings, highways, bridges, sewerage and water systems, etc. A secondary field involves the erection of refinery units, towers, and tanks and the installation of air-conditioning systems, boilers, and power-generating equipment.

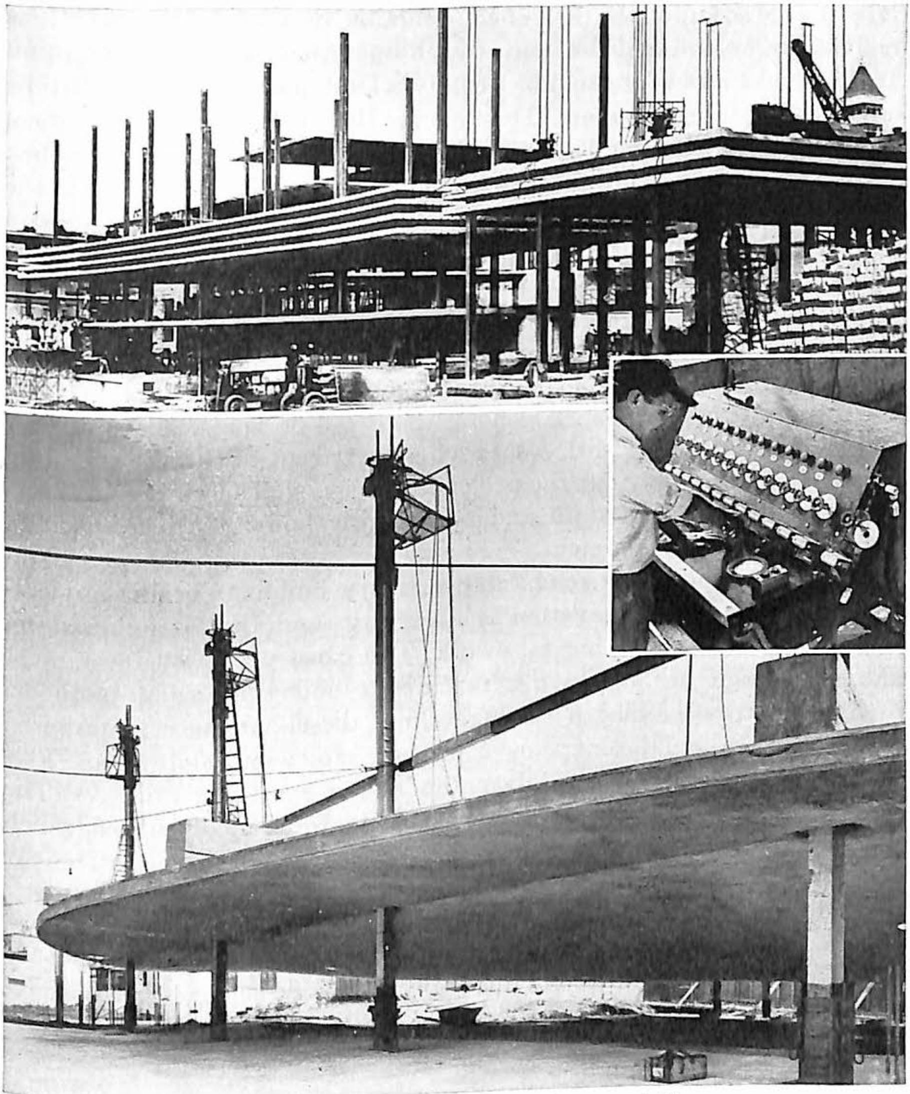
Heavy Construction

From the time plans are first received for bid until the dedication ceremonies are finally held, the construction engineer is active.

Estimating and Bidding. It has been pointed out that ability to predict cost is one of the distinguishing characteristics of the engineer. Nowhere is this more true than in construction. When plans for a large job are received, the construction company's top engineers are called into conference. The project as a whole is discussed, and then it may be broken down into parts for further consideration by specialists.

The first step is to plan the most economical construction procedure. On a hydroelectric plant project, for example, the questions to be answered might include the following: What structure will be required to reroute the stream during construction? How much soil must be removed before a suitable bedding is reached? What type of machinery will do this job best under the circumstances? What is the best location for the concrete plant? What is the best source of sand and rock? What money-saving methods can be employed in placing the concrete? in constructing forms? in removing forms? What facilities will be needed to house and feed the workers? provide recreation? repair mechanical equipment?

Simultaneously with formulating the plan of construction, estimators are performing "quantity take-off." This consists of calculating and estimating the quantities of excavation, formwork, concrete, reinforcing, piping, etc. Each company keeps careful records which provide a basis for estimating unit costs, for example, the cost of placing 1 yd of concrete or fabricating 1 sq ft of formwork under specified conditions. Since each job is different, these are estimates only, and a great deal of judgment based on experience is required.



New Methods of Construction Save Time and Money

One of the responsibilities of the construction engineer is devising new methods which can be taken advantage of by the designer. In one new method the floor slabs are poured on top of each other and then jacked into position. In the upper picture, several slabs have been raised to intermediate positions while construction of first-floor walls proceeds. In the lower picture a one million-pound roof slab is being jacked into position by hydraulic jacks mounted on top of the columns. Inset shows the lift operator precisely controlling the upward movement of the reinforced concrete slab. How many advantages for this method can you cite? Five is good; eight, excellent. (*Vogtborg Lift-Slab Corporation.*)

Having agreed upon the plan of construction, determined the quantities involved, and estimated the cost of each operation, the company is prepared to make a bid for the job. Usually a large part of the work will be performed by subcontractors. The bids for the electrical and mechanical work, etc., must be carefully checked to ensure their adequacy, and then they are incorporated into the general bid. This is a critical moment in the project, and the office is the scene of frantic checking and rechecking and last-minute changes. If the bid is too high, all this work is for naught. If the bid is too low, the company may face financial ruin. In general several companies are pitting their construction skill and financial judgment against each other in bidding for the contract.

Field Work. Once the contract has been signed, a project organization is set up and work begins. In general there will be field work and office work. Field work starts with a surveying party sent to the site to obtain additional data and lay out the project as designed. The survey crew sets grades, determines cut and fill, and locates critical points such as boltholes for major pieces of equipment.

Construction of access roads and auxiliary buildings begins immediately. Usually some excavation is necessary, and that is followed by erection of forms and other falsework. The construction engineer must take advantage of laborsaving machinery and timesaving methods. Modern construction makes use of gasoline-, diesel-, and electric-powered trucks, tractors, bulldozers, shovels, cranes, cableways, and pumps. Prefabrication, tilt-up, and lift-slab methods have special advantages. The construction engineer advises the designer regarding modifications which will facilitate construction or improve the structure without adversely affecting its operation.

In addition to working with materials, machines, and methods, a primary responsibility of the construction engineer is men. Obviously every project is a team effort, and the selection of capable supervisors and foremen is extremely important. The safety and welfare of the individual workers must be ensured. Relations with the unions representing the various crafts must be effective.

Office Work. The office engineer does drafting, calculating, and accounting. The plans frequently need interpretation and clarification, and auxiliary drawings may be prepared. Also, "as-constructed" plans are prepared where the finished structure differs from the original drawing. Progress reports indicate the rate of completion of various portions of the project and form the basis for partial payments to subcontractors. In addition to having a detailed knowledge of the plans and specifications, the engineer must be familiar with construction procedures and costs.

The project manager supervises the work of the construction engineers, but his primary responsibilities are of a nontechnical nature. He does trouble shooting at a high administrative level, solves right-of-way problems, and maintains good public relations. He keeps an eye on the subcontractors and tries to prevent difficulties from getting to the lawsuit stage.

Mechanical Construction

The over-all problems involved in the erection of a refinery unit or the installation of an air-conditioning system are similar to those in heavy construction. There is the same emphasis on careful planning of procedure, development of timesaving methods, use of laborsaving machines, and efficient teamwork among the various craftsmen. The estimating and bidding procedures are similar also.

The major difference is that this type of construction involves more placing and assembling of complete units which have been fabricated elsewhere. Piping, ductwork, wiring, and controls are important, and the engineer on this type of job needs a strong background in electrical and mechanical practice.

Requirements for Work in Construction

Some large organizations combine design and construction functions and operate under the title of "engineer-contractor." Actually, however, the personal qualifications and training required are quite different for the two functions.

Personal Qualifications. The research, development, and design engineers work in idealized situations or on paper. The construction engineer is concerned with the real thing. He is continually working under pressure, and overtime is accepted practice. He must get the work done with what is available. He must take risks, make decisions, go ahead, and learn by mistakes. He must be ready to move anywhere, any time and live under all sorts of conditions. His most difficult problems require a technical background, but his ability to work with people determines his success or failure.

Training. A basic engineering-degree program will provide the necessary knowledge of materials, forces, structures, and electrical and mechanical equipment. Skill in writing reports is important. A background in business law, economics, psychology, and labor relations is desirable. Training in construction methods and equipment may be available in college, or it may have to be gained on the job. In any event construction engineering requires experience and judgment which can be obtained only through actual practice. The typical starting positions such as surveyor, inspector, or timekeeper provide the young construction engineer with an opportunity to gain this essential "postgraduate" training.

PRODUCTION*

The price at which an article can be sold is fixed by competition in the open market. On the other hand, the cost of raw materials and labor is fixed. Whether or not a company can operate at a profit depends on its ability to perform the conversion of raw materials to finished product more efficiently than its competitors. This conversion is the responsibility of the production engineer.

The work of the production engineer is quite similar to that of the construction engineer. In the usual company organization production is directly under management rather than under engineering. The emphasis is on *how* to accomplish after the design engineer has specified *what* to accomplish. The production department advises the design engineers on designing for production, plans the production, and provides for testing and inspection.

Advising Design

While it is essential for the design engineer to be familiar with the capabilities and limitations of fabrication processes, he cannot afford to take time to become expert. The production engineer advises on materials, processes, and procedures. If a particular material is in short supply, he suggests an alternate. If the proposed corrosion-resistant material is difficult to fabricate in the specified manner, he may suggest a change in material or a change in process. The production engineer must be able to predict the effect on cost and time of reducing the allowable tolerance from ±0.002 to ±0.001 in. Frequently a small change in design will greatly facilitate assembly and therefore reduce cost.

Process Planning

In the case of a mass-production item, a great deal of attention is given to selecting the fabrication processes, the major fabrication steps, and the sequence to be followed. Each process has its advantages and limitations. Sand casting is good for mass production but expensive for a few units and results in a rough finish. Die casting gives precise results and smooth finishes but is usually limited to small items and relatively weak materials. Machine tools such as the lathe, milling machine, and shaper are capable of precise work but require a skilled operator, and output is rela-

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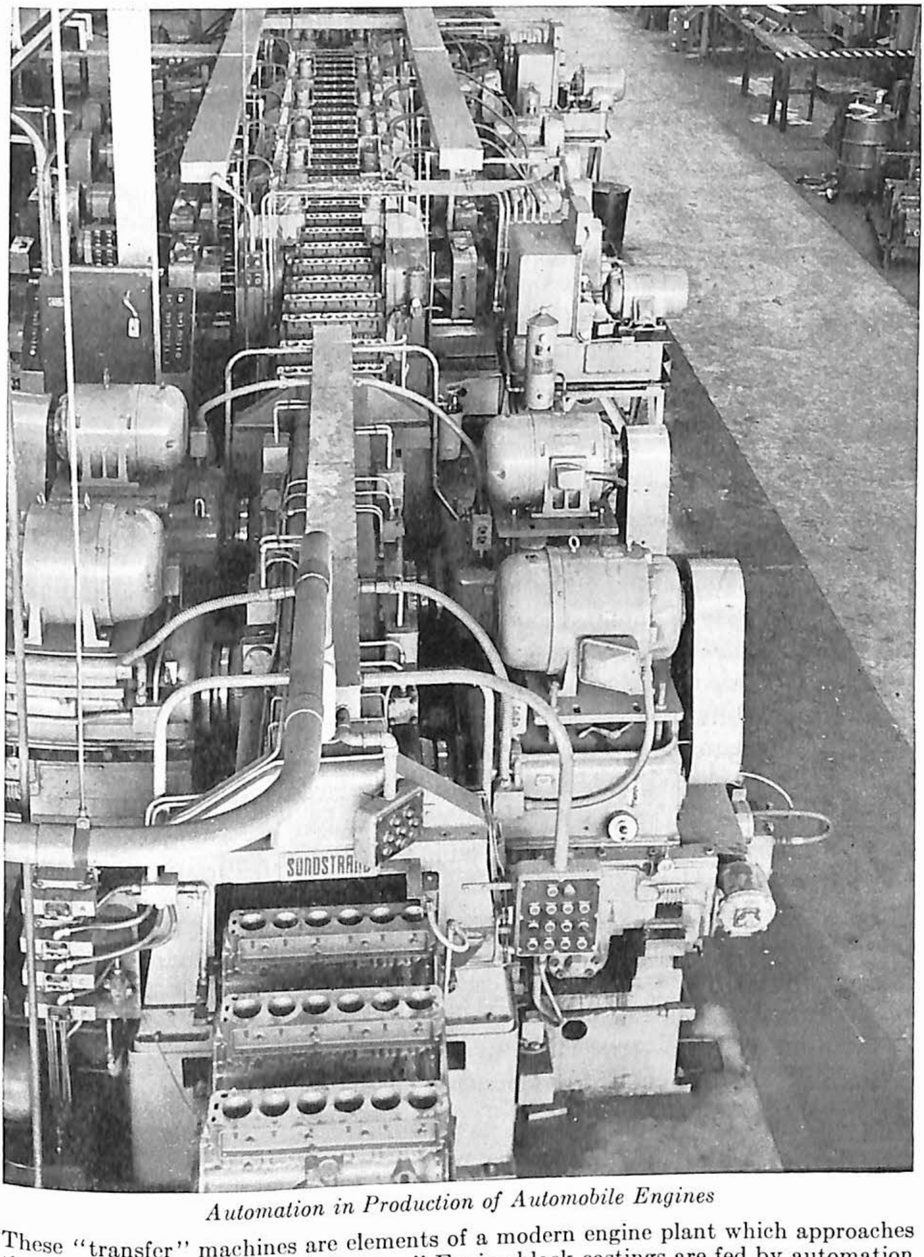
* The terms "production," "tool," "industrial," and "management" engineering are used differently by various authorities. Each is sometimes used as the broad category with the others representing subdivisions. In this text management, industrial, and production are considered coordinate functions with tool engineering as a subdivision of production. The author believes that significant differences exist in the activities of and desirable aptitudes for these three functions.



Automation in Production of Automobile Engines

These "transfer" machines are elements of a modern engine plant which approaches the concept of an "automatic factory." Engine-block castings are fed by automation into the five-station machine in the foreground which mills both ends. The 30-station machine in the background performs a series of milling, drilling, chamfering, and tapping operations. In the automatic factory, all scheduling, materials handling, machining operations, and inspections will be completely automatic; technicians will be required for installation, preventive maintenance, and repair, but the lathe or milling-machine operator as such will be gone. (*Ford Motor Company.*)

tively slow. Automatic machines increase the output but are prohibitively expensive except for mass production. Light sheet metal can be formed readily by presses or brakes, and heavier sheets can be cut and welded, but this is a relatively slow process more adaptable to small-quantity production.

The production engineer must decide on the individual processes and the combinations of processes in fabricating each component, always working within the limitations of the equipment on hand or prepared to justify the purchase of a new machine. The over-all production sequence must take into consideration the routing of raw materials and subassemblies. In every decision he must seek the specified result at the lowest possible cost.

Tool Engineering

One characteristic which distinguishes man from animals is his use of tools. Sometimes production engineering is referred to as "tool engineering," but more properly tool engineering is the phase of production which has to do with major and accessory tools. The major machine tools represent investments of many thousands of dollars; even a small precision lathe and accessories may cost as much as a six-room house. To recover the investments on a given machine requires efficient utilization—utilization at a maximum rate and for those processes which it does best. The production engineer makes replacement studies to determine the point in the life of a machine at which it should be replaced by a new or improved tool.

One important phase of production is tool design. Cutting and forming tools are usually designed and built on the job, whereas the major tools are usually purchased outside. Dies are required for stamping, forming, drawing, and extruding. Cutters for lathes, mills, and shapers may make use of the new, long-lasting carbides in order to reduce costs of high-speed production. Special fixtures are designed to hold work in position, and jigs are employed to guide the tools, thus cutting down time and permitting the use of less skilled operators.

Production Scheduling

The production department must work closely with the sales department and the purchasing department. The flow of raw materials, parts, subassemblies, and completed units must be integrated with the market demand. In the automotive industry this scheduling becomes extremely complex, and automatic business machines have been developed to handle the mass of data. In the near future your purchase of a new car of a certain model and color and your choice of accessories may be recorded in the form of a punched card. Feeding the card into a machine in Texas will automatically result in the necessary orders to assembly in Detroit, purchasing in New York, a supplier in Akron, etc.

Until this comes true in the large industries and for a long time in the small plants, the production engineer must organize scheduling systems which provide for inventory control, order dispatching, equipment scheduling, optimum machine loading, and quality control. If not well planned, these operations may cost more than the actual production itself. Frequently the production engineer must break "bottlenecks." Sales is crying for more output, maintenance demands more time for repairs, purchasing reports that certain materials are unobtainable, management objects to so much overtime, and just then engineering insists on making some design changes. It is under circumstances like these that the production engineer earns his salary.

Requirements for Production Work

It has been pointed out that the functions of production and construction are much alike, and as would be expected, the desirable qualifications are quite similar.

Personal Qualifications. The production engineer works under constant pressure and deals with machines and systems which are pushed to the limit. A feeling for what machines and men can do is important. This is a good job for a planner, but it is no place for a worrier. Roaming throughout the plant involves more physical activity than design. Ability to cooperate with subordinates and representatives of other departments is essential. The ability to sell an idea to management is extremely important when that idea involves the investment of thousands of dollars.

Training. The technical problems faced by the modern production engineer cover practically all phases of engineering, so strong training in the basic engineering sciences is required. In addition specialized training is needed in production processes, metallurgy and heat treatment, engineering economy, and quality control. Practical training may be obtained in college laboratories, on visits to plants, or in vacation work. Starting assignments are frequently in the shop where production operations may be observed.

INDUSTRIAL*

The work of the production engineer involves *things*—machines, tools, plants, products. The manufacturing problems which involve *men* primarily we shall place in the province of the industrial engineer. The economic problems of manufacture excepting those directly concerned with production equipment will also be assigned to the industrial engineer.

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* See footnote, p. 61.

In many organizations the same individual performs both jobs, especially in small companies. However, the functions are sufficiently distinct as to require different qualifications and training and therefore justify separate discussions.

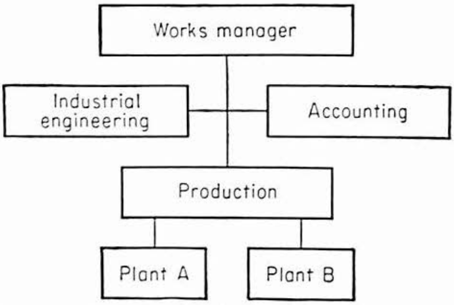


FIG. 6-1. Simplified organization chart.

Industrial engineering is a so-called "staff" function, which operates in an advisory capacity, in contrast to a "line" function, which has direct authority over some operation. On an organization chart this might be shown as indicated in Figure 6-1. This means that emphasis must be placed on cooperation, since the industrial engineering department has no power to direct that action be taken on recommendations concerning methods, standards, job evaluation, training, or costs.

Methods

Frederick W. Taylor is generally regarded as the father of industrial engineering because of his experimental studies (1875–1900) to obtain factual data on worker output. The work of the methods engineer has become popular knowledge as a result of the book "Cheaper by the Dozen."* Gilbreth's success in reducing the work required in laying bricks encouraged him to apply similar methods in raising his 12 children, frequently with humorous results.

Methods engineering is an attempt to apply the same scientific approach to operations involving humans as has been applied so successfully to machines. Motion studies are made in order to minimize effort and eliminate energy- or time-wasting movements. Individual workplaces are designed so that the proper tools are readily available, materials are accessible, and the worker is comfortable and safe. The industrial engineer advises in the design of jigs and fixtures to ensure that human factors are considered. Materials-handling methods and the whole plant layout should be the result of scientific analysis rather than tradition or whim.

Performance Standards

What performance can be expected of an average qualified worker in a given operation? Time studies may be used by the industrial engineer as a basis for determining standards of work performance. These may be used in conjunction with motion studies in comparing current methods

* Frank Gilbreth, Jr., and Ernestine G. Carey, "Cheaper by the Dozen," Thomas Y. Crowell Company, New York, 1948.

with proposed new methods. Sometimes the industrial engineer finds use for Gilbreth's "micromotion" approach in which a motion picture is taken of the operation and then reviewed at leisure. The operator is pictured against a cross-sectioned background with a clock timer in the foreground.

With a complete file of data on the components of various operations and the effects of fatigue and other allowances, it is possible to check on current operations, estimate time required for new operations, and set fair rates of pay. Hourly rates may be standardized, or various types of incentive systems based on quantity and/or quality may be more desirable. Premium systems may reward individual workers or be used to promote teamwork on assembly-line operation.

Job Evaluation

How should the pay of a plant electrician compare with that of a tool-and diemaker, assuming that each does a fair day's work? Since efficiency in production depends so much upon the attitudes of the workers, the rates of pay must be accepted as fair. One responsibility of the industrial engineer may be to develop a basis for comparing jobs in terms of responsibility, training required, physical hardship, etc. When appropriate scales have been developed, each job can be evaluated and that evaluation interpreted in terms of pay.

In most large industrial plants the workers are organized into unions. All matters of performance and pay are the joint concern of management and labor. Frequently the industrial engineer represents management in talks with union representatives. Occasionally the engineer's problems arise out of "grievances" regarding working conditions, performance standards, or pay rates. The successful industrial engineer solves labor problems before they become the cause for strikes or other drastic action.

Training

One method of increasing efficiency is to make sure that every worker knows what he is supposed to do and how to do it. Training is always required when a plant shifts over to a new operation or a new procedure. A new method which shows great promise may be a complete failure if the operators are not properly oriented. Management as represented by foremen and supervisors may need training in carrying out supervisory responsibilities. The industrial engineer may have to educate labor representatives in regard to the merits of a proposed plan.

Cost Control

No modern plant can stay in business without cost control. From the time the raw materials enter the plant until the finished product is on its way to the customer, a careful accounting must be kept of all incident costs. The industrial engineer must understand cost accounting so that he can interpret excessive costs in terms of faulty plant operation. The trend in modern practice is toward standard costs, which are estimates of what costs should be under ideal conditions. They provide a measure of accomplishment and point the way to lower production costs. Detailed statistics and cost records are important tools of the industrial engineer.

Operations Research

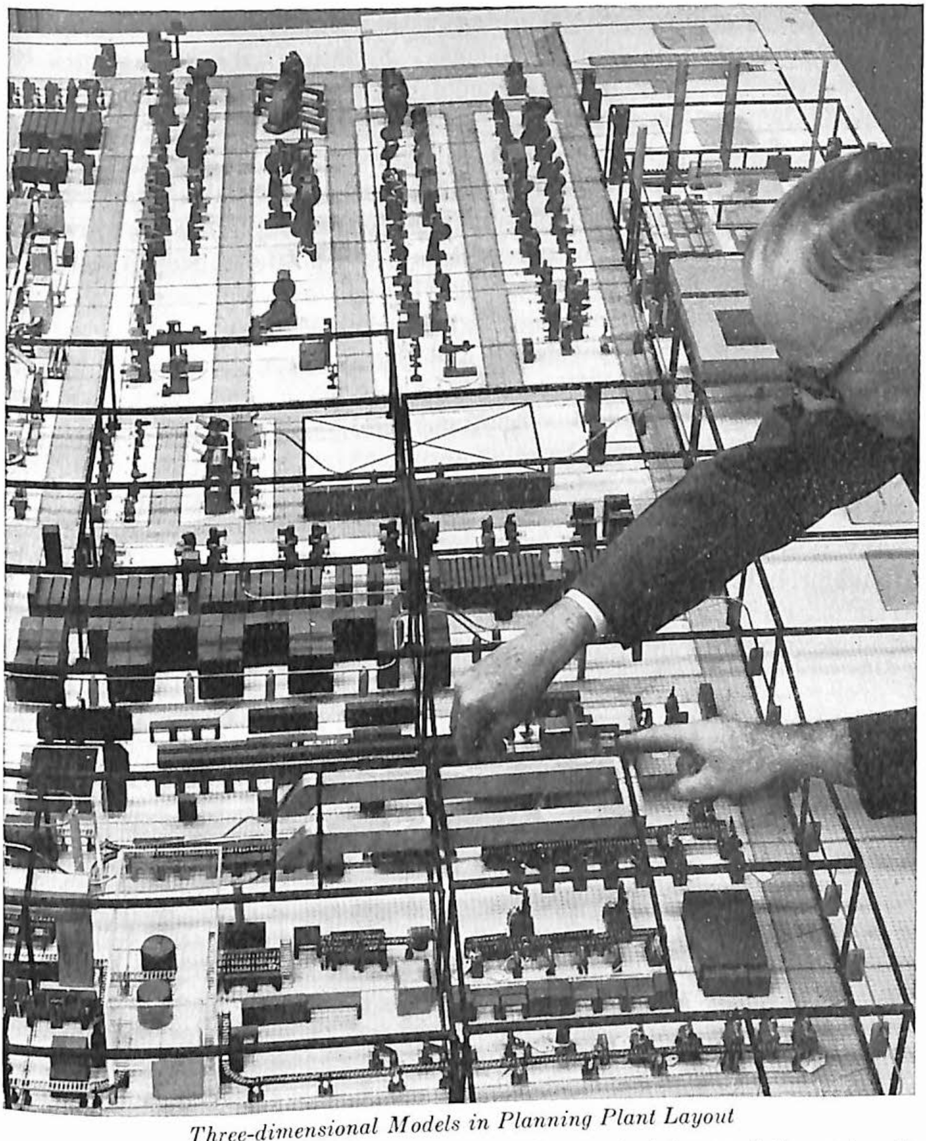
During World War II certain complex problems concerning military operations were turned over to groups of scientists for solution. The success of these nonmilitary specialists in applying basic research techniques to broad, over-all problems aroused the interest of businessmen who found that the scientific approach worked in business operations as well. As a result operations research has become an important tool of modern management, and in many respects, it lies close to or within the province of industrial engineering.

Without attempting to define operations research, we can say that it involves application of the scientific method to over-all problems. Examples include answering questions such as: How large a bomber group should be deployed against a given concentration of enemy artillery? In what pattern and along what route should convoyed freighters be sent to minimize destruction by enemy submarines? Where should advertising dollars be spent to achieve maximum sales? What is the optimum number of each manufactured item to be kept in stock? What is the optimum period for aircraft-engine overhauls?

Note first that these are broad problems involving such a large number of variables and such complex relationships that "common sense" or "simple arithmetic" cannot provide adequate decisions. Second, the problems are so diverse that a team of specialists including mathematicians, psychologists, statisticians, businessmen, and/or engineers may be required; with such a team, the most valuable research techniques (including experimentation) from all fields become available. Note also that the results of operations research provide a scientific, factual basis for decision, but the decision usually must be made by an expert in the field. Management may, in the future, be looking to industrial engineers for scientific assistance in making decisions.

Requirements for Industrial Work

Industrial engineering as a separate function is relatively new. The first persons in this work were usually mechanical engineers, persons trained in business, or production workers. The important requirement was, and still is, ability in working with people—solving problems in which the human factor is important. The personal qualifications and training reflect this emphasis.



Three-dimensional Models in Planning Plant Layout

Plant layout, scientifically conceived and properly executed, is one of the engineer's most valuable methods for reducing manufacturing costs. It is a visual representation of all manufacturing planning, not just a shuffling of machine models on a checkered sheet. An effective plant layout establishes good working conditions, provides a smooth flow of work, and minimizes the handling of materials. It provides for future expansion, contraction, or change in manufacturing method with a minimum of dislocation. (*General Electric Company.*)

Personal Qualifications. Working with irritated or angry people—possibly angry to the point of violence—the industrial engineer must be able to keep his own temper under control. Since he works in an advisory capacity, he must be able to obtain the cooperation of others. He must inspire confidence in his fairness as well as in his ability. He must be able to express his ideas and convince others of their merit. He must be able to solve problems which cannot be handled on the slide rule or reduced to a simple formula, and yet he must retain the scientific approach, employing factual data and sound reasoning wherever possible.

Training. A strong basic engineering training provides the necessary knowledge of materials, machines, and energy. In addition a knowledge of human behavior should be obtained through courses in psychology, industrial relations, and labor relations. Training in economics and cost accounting will be useful in handling problems involving economic factors. A limited knowledge of industrial organization and production operation can be obtained in college but will not replace on-the-job experience. For many positions graduate study in a school of business administration would probably be more valuable than additional technical engineering training. For work in operations research scientific training on the graduate level would be desirable.

OPERATION

After a piece of equipment has been developed, designed, and produced, it still must be operated. Any modern 4-year-old can operate a television set, and most 16-year-olds claim they can operate an automobile. However, the operation of a television station or a steam power plant requires engineering training. In a manufacturing operation the supervision of the manufacturing facilities—buildings, equipment, utilities, etc.—is called "plant engineering." The control of public utilities or processing plants in order to obtain maximum reliability and economy is called "operation engineering." In both activities the maintenance of plants and equipment is of sufficient importance to justify special discussion.

Plant Engineering

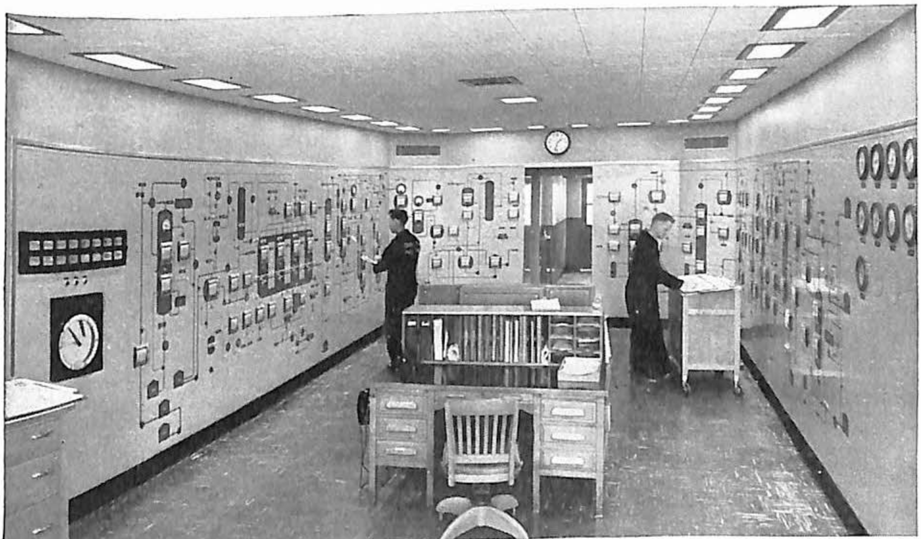
Suppose that you, a plant engineer, are awakened some early morning by a call for help. "Get over here as fast as you can. Unit Number Five has gone off production and it's costing us $500 an hour." The first question is: What is wrong? Is it a failure in power or controls, or has a major component of the unit failed? Once the difficulty has been located, the next question is: Should the defective element be repaired, or should it be replaced? The answer to this question must be on a dollars-and-cents basis, taking into account a great many economic factors. Once the unit is back in operation the question is: How could proper inspection and routine maintenance have prevented this costly breakdown?

The plant engineering department is a staff organization whose function is to provide service to the producing departments. In general, efficiency and dependability of operation are the principal objectives, but they must be expressed in terms of economics. In some types of processing plants, for example, bakeries and glass plants, efficiency must be sacrificed in order to secure dependability and avoid service interruptions.

The plant engineer plans new facilities, supervises their construction, selects and installs equipment, and supervises the operation and maintenance of the facilities. He is usually responsible for plant safety, including safeguards for the individual workers and provisions for fire prevention and fire fighting. His crew includes electricians, plumbers, pipefitters, millwrights, instrumentmen, and other craftsmen and technicians.

Operation Engineering

A small percentage increase in the amount of aviation gasoline obtained from crude oil in a cracking plant may amount to a million dollars in a year. A slight reduction in the amount of fuel oil burned for each kilowatt-



Operating Control Room for Phenol and Acetone Plant

Operations of a complex chemical processing plant are indicated continuously and recorded permanently in this modern control room. Operating engineers determine rates of flow and physical conditions such as temperature and pressure to secure the desired performance and yield. Changes in operating conditions are studied to determine what maintenance is necessary. (*Standard Oil Co. of California.*)

hour of electrical energy produced in a steam power plant may make the difference between profit and loss. Many of the engineers employed by power companies, refineries, waterworks, or telephone companies are primarily engaged in operation.

In a large steam power plant the operation engineer's duties might include keeping in close touch with daily operation, analyzing actual operating data and comparing it with design values, advising design engineers on troublesome features and desirable improvements, gathering data for special studies and recommendations; investigating trouble reports and providing liaison with equipment manufacturers, supervising installation of new units or construction of new plants, and setting up inspection and maintenance procedures. Use of nuclear power plants will bring a host of new operating problems requiring engineering analysis and solution.

Maintenance Engineering

It was estimated recently that for every industrial worker there is \$15,000 invested in machines and equipment. Obviously no organization can afford to let such an investment go unprotected. While the actual maintenance will be in the hands of skilled craftsmen and technicians, the planning and supervision requires engineering. Maintenance is always a responsibility of operation and in many cases is supervised by the plant engineer or the operating department.

Aeronautical maintenance is a highly developed engineering activity of special interest. In most situations, breakdowns are costly and should be minimized. In the air transportation industry, however, the failure of a single part may lead to a catastrophe. Elaborate procedures have been devised to ensure that critical parts are replaced before failure. During operation, tests are performed to check the over-all condition of components. Complete overhauls are scheduled after a specified number of hours of operation. In an engine overhaul, the engine is completely disassembled and every part is inspected. Certain parts are replaced regardless of apparent condition. Other parts are examined using Magnaflux or Zyglo equipment which reveals cracks invisible to the naked eye. X-ray inspection is used on castings and weldments to make sure there are no internal imperfections which could cause failure.

In all operation and maintenance work, the keeping of complete, accurate records is essential. Frequent analysis of records of performance or failure permits modifying the operating conditions for greater reliability or efficiency. On the basis of the data, design changes are recommended. A large aircraft-maintenance base will include an "engineering" department which provides design and drafting service for the operating and maintenance departments.

Requirements for Operation and Maintenance

The operation engineer is more concerned with the performance of actual machines and systems than are the engineers engaged in other functions. This emphasis is reflected in the characteristics of the successful engineer in this activity.

Personal Qualifications. This is the function for the person who likes machines and enjoys trying to get the very most out of them. He should be able to tackle difficult problems and work under pressure. He must be able to get a lot out of men as well as machines. He supplies the leadership and the brainwork for a crew of craftsmen or technicians who have the know-how and manual skill. He should be methodical, good in planning, skilled in gathering and analyzing operating data, and able to translate technical situations into economic terms. Because he performs a service function, he must be able to cooperate with the other departments of the organization. Ability to work with abstract scientific or mathematical concepts is of minor importance.

Training. As with most functions, the work in operations and maintenance covers all the basic fields of engineering—civil, electrical, mechanical, chemical, metallurgical. Experience with actual machines, power sources, and controls may be obtained in the college laboratories but must be supplemented by on-the-job training. The college work should include a background in economy, and statistics would be valuable in many positions. Summer work in some of the skilled crafts would be excellent preparation for positions in this function.

APPLICATION AND SALES

One of the duties of the operation engineer is to select equipment and machines. For much of his technical information he relies upon the sales engineers representing the various manufacturers. Sales is the vital link between the production of a technical item and the operation wherein it becomes useful in the field of engineering equipment. The day of the glib salesman whose major attributes were a smooth tongue and a large entertainment fund is over; in most cases he has been replaced by an engineering graduate who knows the technical capabilities and limitations of his products and through that knowledge is able to improve his customers' operations. Where major pieces of equipment are involved, the sales engineer is supported by technical specialists called application engineers and field representatives called service engineers.

Sales Engineering

The problems of the sales engineer usually arise as a result of a customer's need. The representative of an electrical manufacturer may receive a call as follows: "We've just placed another processing line in operation, and our main transformers are overheating. What can we do about it?" The sales engineer visits the plant, studies the equipment being operated, and examines the monthly meter readings. Frequently in a situation like this the cause is what is called low power factor due to some equipment drawing a relatively high current for a given power. Instead of replacing the transformers, the sales engineer can show the economic justification of placing on the line electrical capacitors which will improve the power factor, eliminate transformer overheating, and probably result in a lower monthly power bill.

This example is typical of many in which the sales engineer must first solve the technical problem, then specify the equipment which will accomplish the desired result, and finally sell the customer on the economic desirability of the solution he presents. The technical work may vary from merely recommending the proper size for a fuse to planning an elaborate processing unit complete with power supply, major units, accessories, controls, and instruments. In many respects the sales engineer performs a function similar to that of the architect. Starting from a stated purpose he must combine elements to accomplish that purpose efficiently and reliably. In the broader sense, this is "design." Wherever he can, of course, he uses products of his own company, but his customer's good will is so valuable that he must avoid proposing an inferior unit. Frequently several sales representatives will be quoting on the same job, and his competitors will be quick to point out any weaknesses in his proposal.

The daily work of the sales engineer will include the following: studying his products by means of company literature and operating instructions; traveling between customer's plant, home office, and factories; planning for "creative selling" where a customer may be unaware of his need; analyzing customers' complaints; conferring with company associates and attending sales meetings; representing the company at technical meetings and entertaining important customers; reporting to the design engineers on field problems and innovations by competitors; assisting in collecting on overdue accounts; and reporting on sales progress.

The sales engineer is unique in two respects. In the first place he personally represents the company in many contacts and transactions. He is directly connected with company income, and knowing the market and competition, he influences design and production. Because of this background it is easier for a sales engineer to step up into management than it is for a specialist in the development laboratory or the design office. Second, the sales engineer deals with a wide range of persons—research scientists needing unusual equipment, process engineers with rigid technical specifications, practical men interested only in over-all operation and maintenance, city councilmen interested primarily in cost, etc. The sales engineer must be able to speak with each of these on the appropriate technical level.

Application Engineering

When the products are more complex and involve more highly technical features, there is a tendency for the sales engineer to concentrate on customer contact and turn over the "design" problems to application specialists. These application engineers work in a centralized office and are available as consultants to sales engineers and customers in that market area.

One large electrical manufacturer maintains in major cities offices staffed by specialists in industrial power, chemical and petroleum processing, central station equipment, marine power, or transportation applications. In addition to knowing the standard products, these men are qualified to modify existing designs or design special apparatus to meet special needs. For example, on a wind-tunnel job it was necessary to provide a powerful motor which could be started on a line of limited capacity and yet operate with high efficiency. The design evolved was so satisfactory that it was patented and made available for other installations.

Service Engineering

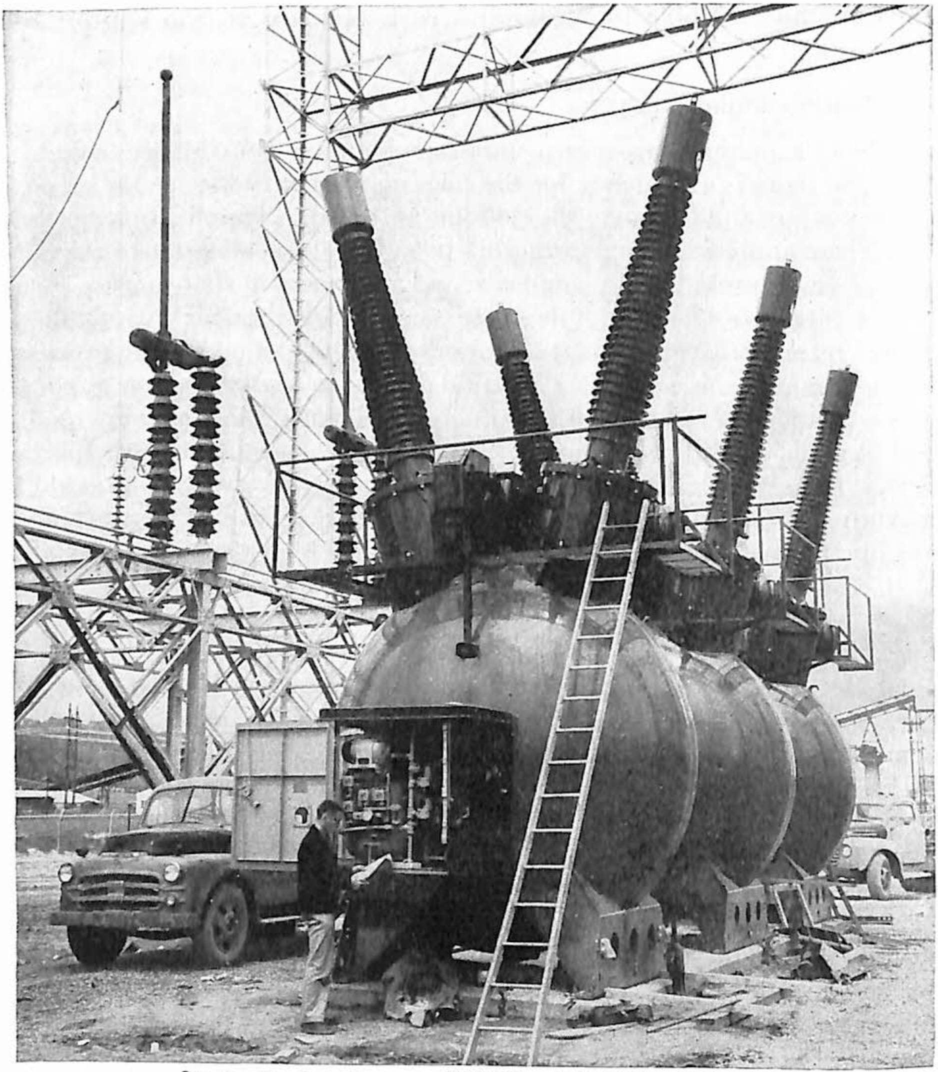
Obviously an elaborate unit of this type cannot be loaded on a freight car, sent off, and forgotten. The performance of the unit and the customers' satisfaction are too dependent upon proper installation and operation. Experience has proved the desirability of including in the contract responsibility for installation, field testing, and operator training.

As soon as the equipment is delivered, the field or service engineer gets on the job. He may use his own men, the contractor's men, or a crew he recruits for the installation. He may have to plan foundations, utility installations, unloading facilities, and erecting methods. After the unit is assembled, he checks each component, making any adjustments necessary and correcting any travel damage. With the assistance of the customer's operators he starts up the unit and checks its performance. Usually he can expect a series of difficulties, and his ability as a trouble shooter is important. He is also responsible for training the customer's crews in proper maintenance procedures.

Requirements for Sales Engineering

While sales, application, and service functions may differ in their responsibilities in a large company, the personal qualifications and training required for all three are quite similar, and in many cases one individual performs all three activities.

Personal Qualifications. The distinguishing characteristic of the so-called "sales personality" is the ability to establish communication with



Service Engineering on a 330,000*-volt Oil Circuit Breaker*

Operation at increasingly higher voltages is possible only when adequate circuit breakers are available. The electric current comes in at one of the insulated terminals at the top, through a transformer inside the short cylindrical section, through three sets of contacts in series, and out the other terminal. A sudden rise of current in the line is relayed by means of the transformer to the interrupter which pulls the contacts apart and forces a powerful blast of cool insulating oil between them. These breakers hold a total of 11,900 gallons of oil and weigh a total of 171,000 pounds (a far cry from the wall switch with which you are familiar). These breakers will interrupt a current of 41,000 amperes in $\frac{1}{20}$ of a second and reclose the circuit within $\frac{1}{3}$ of a second if the line is cleared. A service engineer supervises the unloading, delivery, and erection of the units. He inspects the operating mechanisms and makes final adjustments before field testing the breaker under severe conditions. (*General Electric Company.*)

strangers quickly. The salesman must be friendly, easy to get acquainted with, and a good listener. He should inspire confidence in his knowledge of his product as well as in his business integrity. He should be courteous and tactful. Since he represents his company, his appearance is important. He must be able to interpret his customer's requirements and to express his own ideas effectively. He should have good business sense. He should not mind traveling.

The sales engineer is one who possesses this type of personality and, in addition, the technical ability to solve a wide range of engineering problems including design, operation, and maintenance. He must be ingenious because he is called upon to meet novel situations. He must make field decisions on important matters and run the risk of making mistakes. He must be able to deal with persons on all technical levels.

Training. The sales engineer can expect to work on problems in all fields of engineering, and therefore he needs broad training. Because much of his work is on a highly technical level, an engineering degree is almost mandatory. His training should include the fundamentals of equipment, processes, and controls. Training in business law, accounting, and economics is valuable.

College training does not lead directly to sales. Usually a sales trainee spends two years or so in manufacturing or service departments to become familiar with the products and their characteristics and to develop the necessary judgment. Frequently his first sales assignment will be in conjunction with a more experienced engineer.

MANAGEMENT

A recent survey by the Engineers Joint Council indicated that one third of all engineers of full professional status are employed in the "administrative management" function. Another survey by Columbia University indicated that "forty per cent of industrial management is engineer-trained, replacing both the lawyer and the banker in top industrial posts." A look at the boards of directors and lists of presidents and vice-presidents of the major industrial enterprises such as General Motors, General Electric, United States Steel, and the Bell System reveals that half of the top-management positions are filled by men with engineering training.

What is management, and why are engineers so desirable in management positions? One way of illustrating the relationship of management to the other engineering functions is as follows: Research and development determine *if* a thing can be done, design and production determine *how* a thing can be done best, but management must decide *whether* to do it at all. Management must decide how the assets and capabilities of an organization are to be used. The abilities which characterize a good engineer in other functions are useful in making these decisions.

Purposes, Policies, and Decisions

Management has a threefold responsibility. An obvious responsibility is to the owners: the proprietor, the partners, the stockholders, or the public, depending on the type of organization. It is now generally accepted that management is responsible also to the workers, and no longer is labor regarded as a commodity to be purchased at the lowest price possible. The third major responsibility is to the general public which must benefit from management's operations.

In line with these responsibilities, management must set up the purposes of the enterprise, establish the policies by which these purposes are to be achieved, and make decisions consistent with these policies. Some industrial companies are organized to perform all engineering functions from research to sales, while others concentrate on a narrow range of functions. Some specialize in a particular type of product, while others endeavor to spread their efforts over a wide variety.

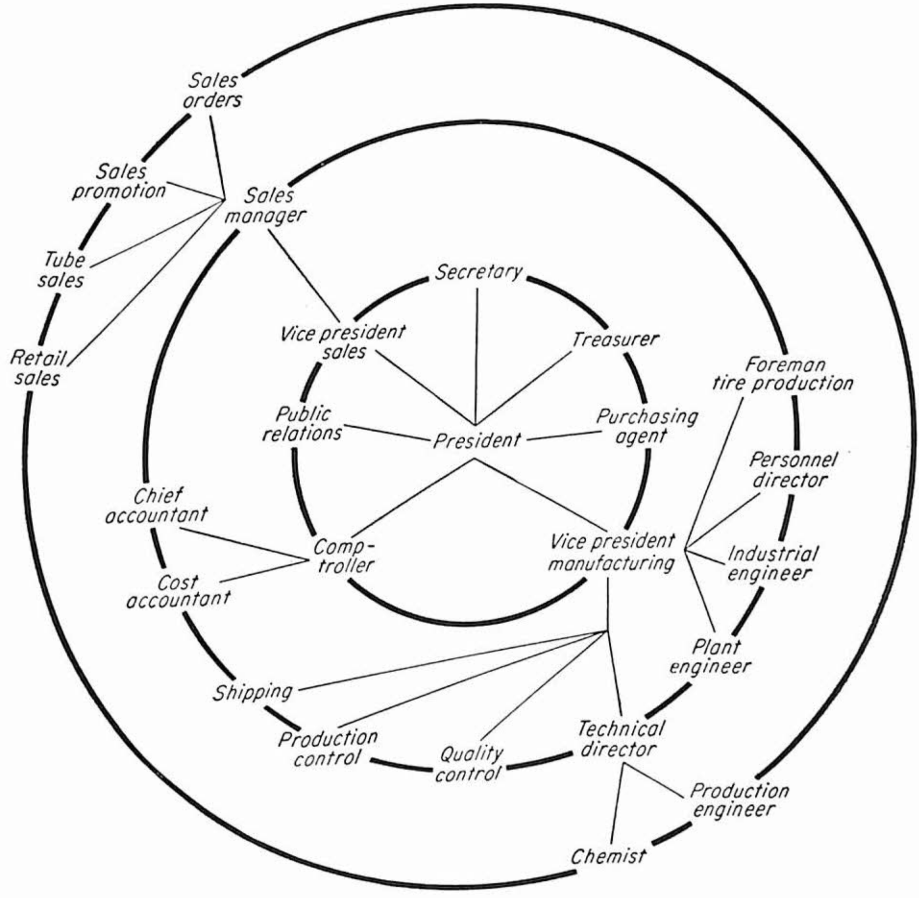
Money

The assets of an enterprise include *money*, *men*, and *things* such as plants, processes, materials, methods, and machines. The responsibility to the owners is primarily in terms of efficient money use. Each year several billion dollars are spent for new plants, additions to existing plants, and modernization of old plants. Capital is available for these purposes in the expectation of earning a profit. Having determined to expand into a new operation, say, management must select a means of financing. This may be done from previous savings, current earnings, or some outside source.

The decisions by management are usually based on data supplied by others. Shall we sponsor a research program in this field? Is it justifiable to conduct a project to develop a new use for this material? Is it time to redesign our major product? Can we afford to expand our production facilities in expectation of greater demand? Shall we undertake an expensive advertising campaign? In each case the management group depends on the various departments for specific information concerning the advantages and disadvantages of a proposal. Usually the information is embodied in a written report accompanied by charts and graphs and, probably, an oral presentation. The ability to write reports and present ideas is of great importance to all creative men, engineers especially.

Men

The work of the enterprise and the ideas which result in progress and profit are contributed by individuals. Management's part consists in selecting, training, and directing men. A well-defined organization plan lists the various components, specifies their duties and responsibilities, indicates their relationships to others, and establishes the authority by which they function. Men are assigned to particular positions on the basis of their abilities or, occasionally, positions are modified in scope to fit the man. Individuals must be trained to increase their effectiveness in current positions and prepared for greater responsibility in future positions. Management always has the duty of directing the abilities and energies of its manpower toward the established objectives of the organization.



Concentric Organization Chart

Lines of authority are indicated, as President—Vice president, manufacturing—Technical director—Production engineer. Public relations is shown as a "staff" department which provides a service without having any authority over other activities. Seven men report directly to the President, and the Vice president, manufacturing, is in direct contact with eight subordinates. A complete organization plan would also specify the duties and responsibilities of each management person. (*After C. G. Brown, The Concentric Organization Chart,* Journal of Applied Psychology, *vol. 34, pp. 375–377, 1950.*)

Things

In a manufacturing organization, for example, most of the decisions involving technical aspects of the operation are made by technical men. Management is concerned with broader problems involving large amounts of money or numbers of men. The adoption of a new major process, the location of a plant, or the replacement of expensive machinery is usually decided at the management level.

Plants, structures, and machines seldom live out their physical life. Long before a machine is worn out, it usually has become economically unusable. The development of better materials, improved processes, and more efficient machines renders old machines obsolete. When should a machine be replaced by a new, more efficient unit? The answer to this question depends on the events of the future and therefore it cannot be stated exactly. The practical answer must be based on judgment developed in the past and prediction for the future. Management policy may be that the cost of a capital investment must be recovered through savings in operating expenses over a 5-year period. Once that decision has been made, engineers can determine if and when replacement is justified.

Requirements for Work in Management

Management is generally recognized as a possible goal for engineers in other functions. The requirements for success in management are indicated by the emphasis on ability to solve problems involving men and money as well as things.

Personal Qualifications. A manager is basically a leader with good business sense. The boy who has been selected by his classmates for school and club offices and has been successful in carrying out the responsibilities of those offices has already demonstrated leadership qualities. Management requires a broad viewpoint, and frequently the manager type is less interested in technical specialization than is the design or research type. He should be interested in social and economic factors as well as scientific factors. Most successful engineers have strong motivations that carry them to the top. For the development engineer the desire for credit and recognition may be the motivating force; the management engineer is usually more interested in position and power. One important characteristic of the manager of men is his sensitivity in human relations, his understanding of the basic desires for security and recognition, his acceptance of the responsibility for contributing to the personal welfare of his employees.

Training. No engineering school gives a course in How to Be a Company President. The usual route is from technical positions through supervisory jobs to management responsibilities. Since it is in the first technical assignments that the young engineer establishes himself, a strong engineering training is essential. Some engineering functions provide a broader experience and therefore are more likely to result in opportunities to enter management. Production is a primary function and directly affects profit; industrial engineers work with men and money and frequently represent management; salesmen represent the company to the customer and are familiar with the market and competition. Each of these and the other engineering functions develop candidates for promotion into management.

THE ENGINEERING SPECTRUM

In general, engineers work with *ideas* (abstract scientific concepts and principles), *things* (machines, materials, structures, circuits), *men* (employees, associates, superiors, customers), and *money* (financing, costs, prices, profits). The relative extent to which engineers use knowledge in the four areas is indicated roughly in Figure 6-2.

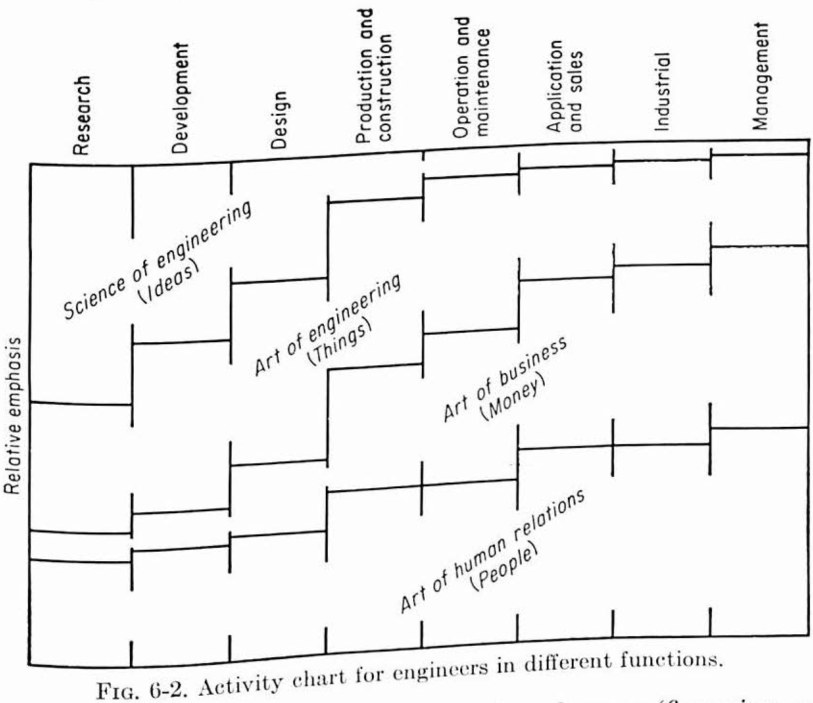


FIG. 6-2. Activity chart for engineers in different functions.

The Engineering Spectrum

The variation in emphasis among the functions of engineering illustrates the fact that engineering is not a single activity but rather a spectrum of activities offering a variety of careers.

This functional classification of engineering is particularly helpful for the beginning student. Right now you should begin thinking about your own aptitudes and personal qualifications and comparing them with the requirements for the various functions. Early in your engineering career you should decide whether you prefer to work with ideas, things, men, or money, and that decision will guide you in your selection of optional courses and help you get the most out of your engineering training.

Rather than restrict your choice to a single function at the present time, you may wish to think in terms of broad areas. Area A in Figure 6-3 represents the highly scientific functions of research, development, and design. What are the distinguishing characteristics required for work in this area? Area B, including construction, production, operation, and maintenance, emphasizes more practical problems. What qualifications should you have here? Area C involves personal relations and contact with people in sales, industrial, and management. Does your past experience indicate that you would be successful here?

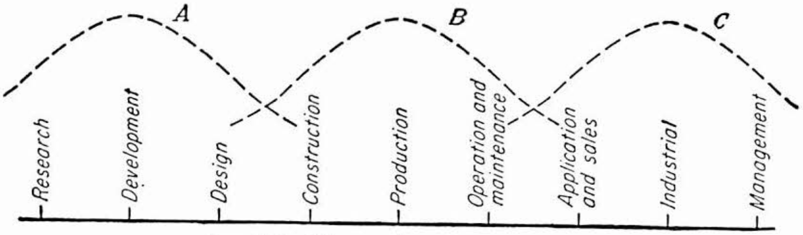


FIG. 6-3. The engineering spectrum.

Branch, Function, and Rank

As was pointed out previously, interest is usually associated with branch of engineering while aptitude and training should determine the preferable function. Defining your choice of career will require two selections; you may decide on electrical-development or chemical-operation or mechanical-design or petroleum-sales, for example.

The title of a practicing engineer must also indicate his rank or the degree of supervision he exercises. Typical rankings are as follows:

Construction Co.:	Manufacturing Co.:	Civil service:
Engineering aid	Engineering assistant	Engineering aid
Inspector	Junior engineer	Junior engineer
Resident engineer	Design engineer	Assistant engineer
Project engineer	Project engineer	Associate engineer
Project manager	Section engineer	Engineer
Construction engineer	Chief design engineer	Senior engineer
Chief engineer	Chief engineer	Chief engineer

Within a given organization these designations would be adequate. However, to be complete a title should specify rank, branch, and function, for example, chief mechanical design engineer or junior refinery operation engineer or resident highway construction engineer.

Can you visualize the work of each of these men? Do you know the duties and responsibilities of each? Do you know the qualifications for each of these positions? If so, you have a good picture of the engineering profession and are in a position to benefit from your engineering training.

SUMMARY OF ENGINEERING FUNCTIONS

Research

The research engineer is seeking new knowledge or a better understanding of known facts. He is seeking new principles, new methods, new processes, new truths. He is working on the frontier of scientific knowledge, and his training must provide a thorough understanding of advanced mathematical and scientific concepts. He must have the ability to reason inductively and in abstract terms and to express himself in new mathematical forms. He should be skilled in analysis.

Development

The job of the development engineer is to apply the discoveries and results of research to some useful purpose. He uses the principles, tools, and techniques made available through research. His efforts usually result in a working model of a circuit or process or machine which has desirable characteristics. The development engineer must be ingenious, creative, and skilled in experimentation and have great initiative and perseverance.

Design

The design engineer takes the result of the development engineer and carries it to the point where it is economically useful. In designing products to be manufactured and sold at a profit, he selects methods of accomplishing desired results, selects materials, and determines shapes to satisfy physical, chemical, electrical, and thermal requirements. The design engineer must have advanced training in the properties and behavior of materials and processes and the ability to adapt recent advances to current practice. He must be skilled in synthesis, proficient in graphical expression and have a strong background in economy.

Construction

The construction engineer is responsible for surveying the site and preparing the location for the structure. He determines the procedures to be followed on the basis of economy and desired quality of the result. He directs the assembly, placing, and joining of materials. He organizes the personnel to carry out these operations. The construction engineer must be skilled in the art of his profession. He must be able to direct people effectively and have a firm grasp of costs.

Production

The work of the production engineer closely parallels the construction function except that it is concerned primarily with products constructed in a factory or other fixed location to be operated elsewhere. He chooses the processes of manufacture, the sequences, the tools, and the methods. He integrates the flow of materials and components with processes. He provides inspection and testing facilities and procedures. He eliminates bottlenecks and corrects faults in manufacturing procedures. He works closely with designers through early stages of production and participates in redesign.

Industrial

The industrial engineer works closely with the production engineer in selecting equipment and laying out the plant, insofar as human and economic factors are concerned. He devises work stations which facilitate human effort and increase production. He writes job descriptions, makes job evaluations, sets standards and rates of pay, and designs incentive pay systems. He operates cost controls, supervises clerical procedures, and forecasts production costs under new conditions. The industrial engineer is primarily concerned with the economic and human factors in production, and his training and personal qualifications must be suitable.

Operation and Maintenance

The operating engineer controls machines, plants, or organizations which provide services such as power, utilities, transportation, communication, or storage. He is responsible for the selection, installation, and maintenance of equipment. As the supervisor of an over-all manufacturing operation he is sometimes called the plant engineer. He is responsible for preventive-maintenance programs and the operation of complex equipment for maximum economy. He determines operating procedures and supervises operating personnel.

Application and Sales

The application engineer analyzes customers' requirements and selects and recommends units to satisfy their specifications most economically. He combines salesmanship with technical education and training in application. He analyzes customers' complaints and trains the customers' operating personnel. He must be able to deal with persons at all technical levels from the maintenance man to the research scientist. The application engineer must be skilled in verbal expression and have a strong business training.

Management

It is the responsibility of management to determine the main purposes of an enterprise and to set up the policies to be followed. The manager sets up the form of organization, the chain of authority, and selects the executive personnel. Engineers have proved valuable in management positions because of their ability in analyzing the factors involved in a problem, collecting the necessary data, and drawing sound conclusions. The primary requirements include a background of engineering fundamentals, skill in human relations, and ability in business.

ASSIGNMENTS

6-1. Select a common article (such as an automobile tire, a vacuum tube, a lubricating oil, or a pump), and familiarize yourself with all phases of the manufacture and use of the article (some library study may be necessary). Mentally classify the engineering performed on this article by function.

Describe, in a brief report, the work done in connection with the selected article in each of *three* engineering functions. This can be done by writing a paragraph on each or by a listing in outline form.

6-2. What are the distinguishing qualifications required for work in area *A* in Figure 6-3? For area *B*? For area *C*?

6-3. List what you feel to be your own personal characteristics and aptitudes, and indicate the function for which you feel best qualified.

6-4. Select an engineering project with which you are familiar, or discuss with an engineer a project in which he was involved. Describe in some detail the work done by an engineer performing a specified function.

7

TECHNICIANS, ENGINEERS, AND SCIENTISTS

The mining engineer pushed back his chair from the conference table and stood up. "So far so good," he said. "If the final report from the geologist supports our preliminary study, we'll put a surveying party on the next plane. From the surveyor's detailed map we can start planning the installation."

The project engineer on the peach slicer was a mechanical engineer with 8 years of design experience. Assigned to his group were a metallurgical engineer, a junior engineer just out of college, a chemist with special training in food chemistry, a draftsman, and a detailer.

The aeronautical research engineer looked over the data submitted by the wind-tunnel operator. After checking on the experimental conditions under which the measurements were made, he agreed that the results should provide the answer to the question which faced them. He hurried over to the computer room and explained to the mathematician in charge of computer-programming the type of analysis he had in mind.

The development engineer quickly sketched out for his electronic technician the vacuum-tube circuit he had in mind. "Build it up 'breadboard' style," he directed, "and see if you can work out some method of controlling the output without affecting the frequency response at the high end. In the meantime, I'll check with our physicist to see what the possibilities are for accomplishing the measuring operation by means of an optical system."

As indicated in these illustrations, the engineer is usually a member of a versatile team of specialists possessing complementary skills and knowledge. The geologist, the chemist, the mathematician, and the physicist are being used in industry in increasing numbers. Working with engineers, these *scientists* bring to bear on practical problems the stores of knowledge in their particular fields. Assisting the engineer in the field, on the drafting board, with complex experimental apparatus, and in the laboratory, the *technicians* make their contribution to America's industrial progress.

Frequently, a high school graduate whose real interest lies in the work of the scientist or the technician enters engineering because the name is more familiar. This is particularly true of the young man whose aptitudes and interests promise success in a career as a technician but who is unaware of the opportunities in the technical fields closely related to engineering. It is the purpose of this chapter to explain the relationship between the engineer and the other members of the industrial team, point out the differences in the required training and qualifications, and describe the employment opportunities available.

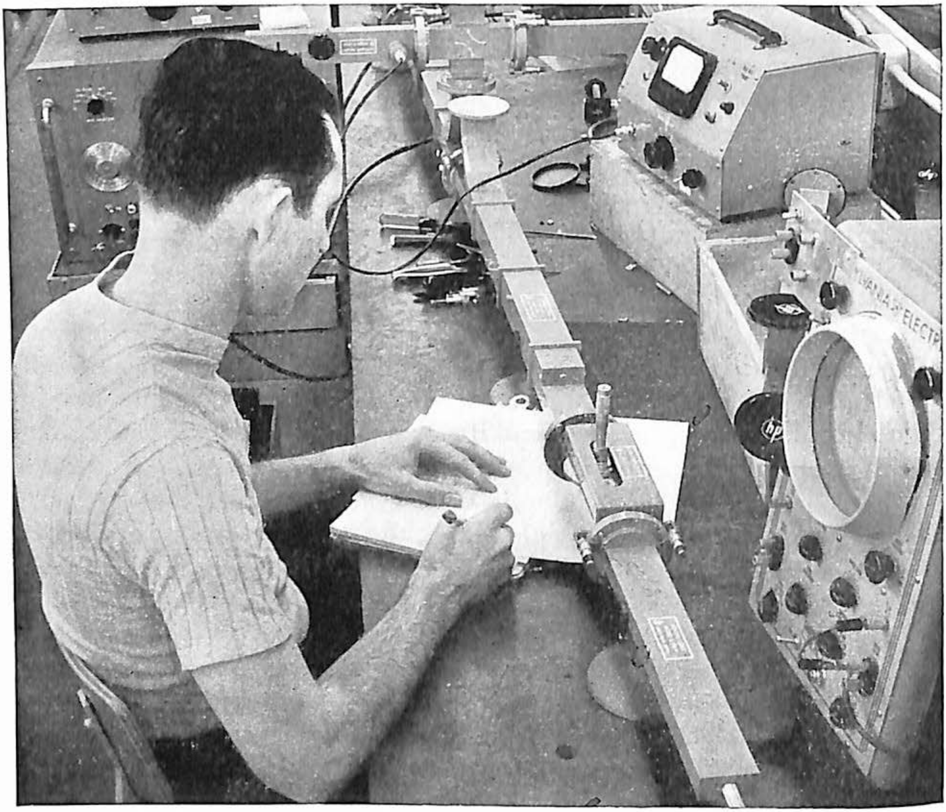
THE TECHNICAL TEAM

The engineer is a man of ideas and a man of action. In preparing himself for effective service in his particular area, he must concentrate on certain types of training and forgo others. He develops mental skills but seldom has the opportunity to develop manual skills. In concentrating on the application of science he can obtain only a limited knowledge of science itself. As technology moves rapidly ahead, the strictly engineering aspects of any project become more and more demanding. As a result, the most effective organization of technical ability is in a team of specialists each of whom makes his particular contribution.

The primary objective of the *scientist* is "to know," to discover new facts, develop new theories, and learn new truths without concern for the practical application of the new knowledge—and, in most cases, without any concern for whether or not a practical application even exists. A secondary activity of scientists involves the use of science and scientific methods and tools. For many years the practicing geologist and the industrial chemist have worked side by side with engineers, contributing their specialized knowledge in the solution of engineering problems. More recently the mathematician and physicist have been called upon to assist in the increasingly scientific technology.

The *engineer* has primary responsibility for designing and planning research programs, development projects, industrial plants, production procedures, construction methods, sales programs, operation and maintenance procedures, and structures, machines, circuits, and processes. His plans must accomplish a given result, specified by quality and quantity, at a minimum cost in personnel, time, material, and money. One distinguishing characteristic of the engineer is his ability to predict the performance and cost of an over-all plan.

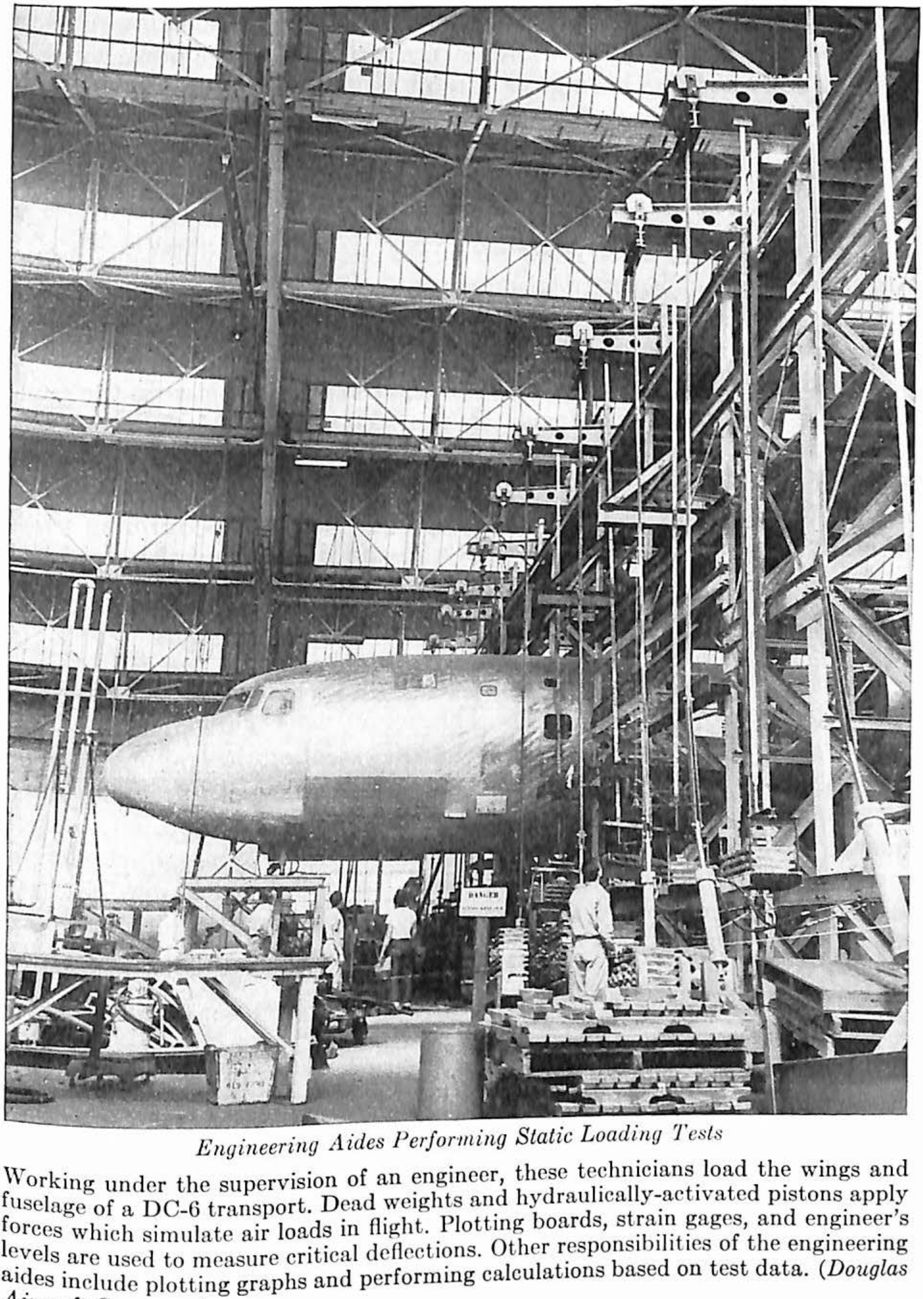
The *technician* usually specializes in one aspect of engineering, becoming a draftsman, a cost estimator, a time-study specialist, an equipment salesman, a trouble shooter on industrial controls, an inspector on technical installations, a constructor of intricate experimental apparatus, or an operator of complex test equipment. Because he specializes, his training can be briefer and more intensive and he becomes productive with less experience. Working with engineers, the technician uses mathematics and science in solving technical problems, he uses precision instruments for making measurements, and he occasionally uses tools for construction.



Production Test of Waveguide Component

A typical activity of the electronic technician in production work is evaluating the performance of complex apparatus. The standard signal generator at the left feeds power into the "directional coupler" under test, which in turn is connected to a load tuned to absorb the output power. To perform this task, the technician must have a qualitative understanding of fields and waves, a quantitative understanding of elementary circuit theory, skill in manipulating test equipment, and ability to interpret experimental data. (*Hewlett-Packard Company*)

It may help to point out that the technician occupies a position intermediate between the engineer and the skilled *craftsman*. The craftsman, such as the electrician, machinist, patternmaker, watchmaker, welder,



Engineering Aides Performing Static Loading Tests

Working under the supervision of an engineer, these technicians load the wings and fuselage of a DC-6 transport. Dead weights and hydraulically-activated pistons apply forces which simulate air loads in flight. Plotting boards, strain gages, and engineer's levels are used to measure critical deflections. Other responsibilities of the engineering aides include plotting graphs and performing calculations based on test data. (*Douglas Aircraft Company.*)

and modelmaker, uses his hands more than his head, tools more than instruments, and mathematics and science rarely. The high degree of skill in using tools and the feeling for careful workmanship have earned the craftsman his important place on the industrial team.

TECHNICIANS

Engineering technicians make up a relatively new occupational group which has become of numerical importance only in the last 20 years. At the present time there are around 200,000 persons in various technician categories. As rapid technological progress forced engineering work to more and more highly scientific levels, a gap appeared between the engineer and the skilled craftsman. In the electronics field, for example, installation, operation, and maintenance of electronic apparatus require a level of technical know-how far beyond that of the experienced electrician. As a matter of fact, the new technicians are performing work which 20 years ago would have been in the province of the electrical engineer.

Typical Technician Positions

Technicians work alongside engineers in a great variety of industries and in all engineering functions. The actual work varies greatly from industry to industry and depends to a great extent on the training, experience, and personal qualifications of the individual. Not infrequently we find technicians doing work that is of engineering level; and, all too frequently, we find qualified engineers carrying on activities which should more properly be handled by technicians. The following sample job titles are grouped according to the engineering function with which they are associated.

Research

Electronic laboratory technician: builds experimental electronic equipment for research engineers.

Instrument technician: installs, maintains, and constructs precision instruments and measuring devices.

Metallurgical aide: collects and prepares statistical test data on metals and alloys.

Development

Development laboratory technician: produces working models of new devices for development engineers.

Engineering aide (development): makes measurements and gathers data on performance of development models.

Pilot-plant operator: operates pilot-plant equipment in development of new products and processes.

Design

Airframe designer: designs airframe components and provides liaison with other departments.

Electrical engineering aide: assists in designing and testing new electrical equipment.

Mechanical draftsman: makes accurate scale drawings of parts and machines from rough sketches and specifications.

Construction

Estimator: computes costs of material and labor from building plans and prepares bids.

Construction inspector: inspects construction materials and methods to ensure conformance with plans and specifications.

Building foreman: supervises specific operations or trades during construction.

Production

Production supervisor: supervises assembly and processing of parts and materials.

Production test technician: tests and inspects manufactured products to ensure conformance with specifications.

Tool designer: designs special tools, jigs, and fixtures used in manufacturing operations.

Operation

Load dispatcher: controls operation of power stations and transmission lines in an electric-power system.

Television-studio technician: operates and controls lights, cameras, and video equipment.

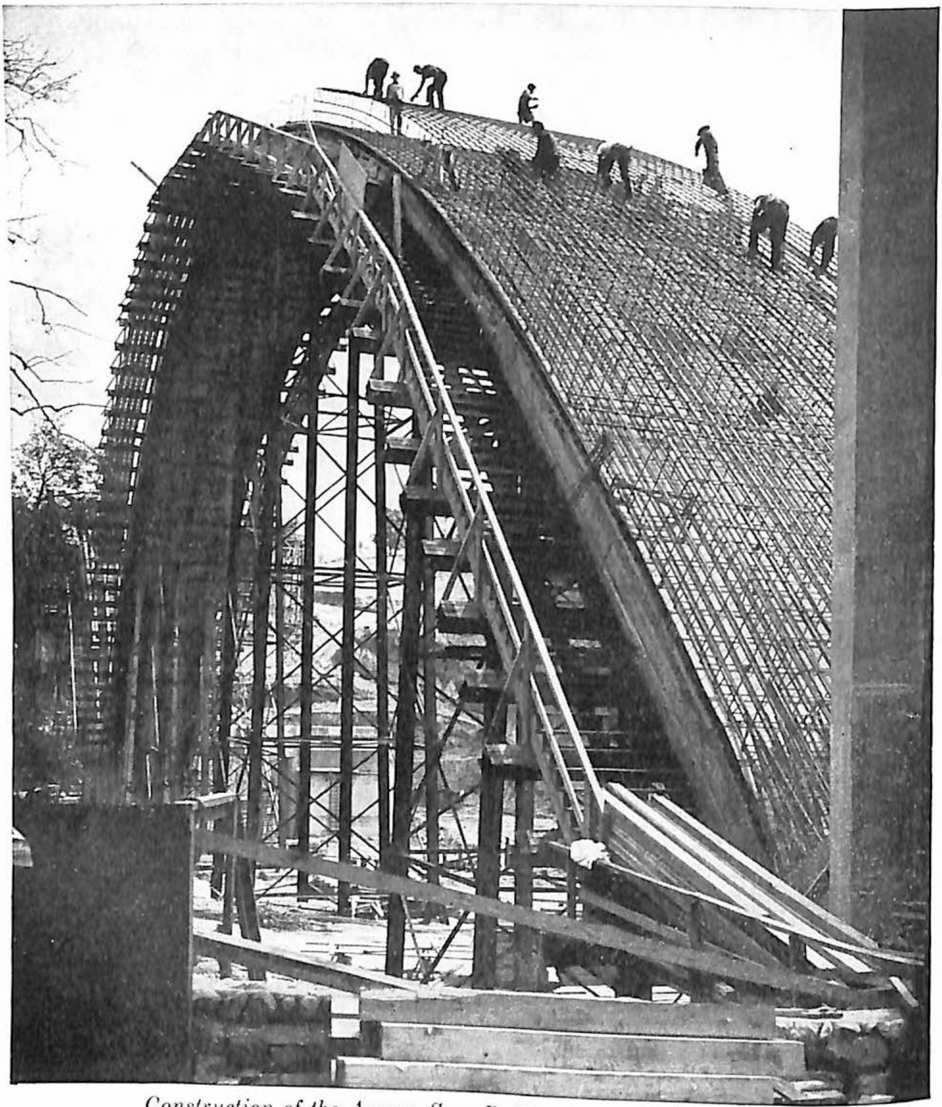
Diesel plant operator: operates and controls diesel-electric generating plants.

Maintenance

Diesel technician: maintains, repairs, and rebuilds large diesel engines.

Aircraft instrument technician: tests, repairs, adjusts, and installs various aircraft instruments.

Air-conditioning technician: installs, maintains, and repairs air-conditioning equipment and controls.



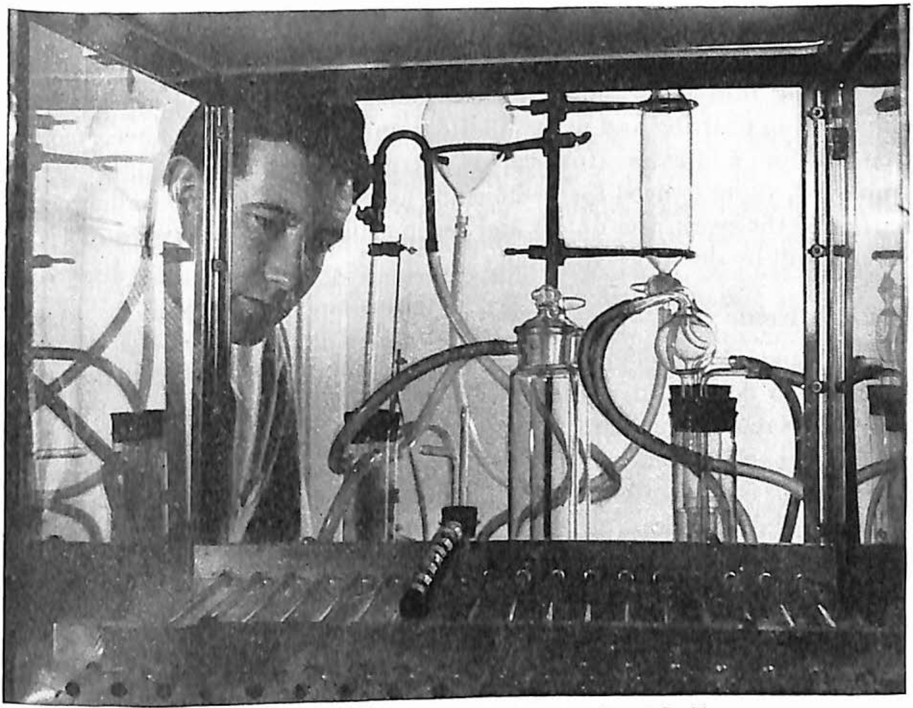
Construction of the Arroyo Seco Bridge, Pasadena, California

This 1,364-foot vehicle bridge is made up of three reinforced concrete arch spans and eight box-girder spans. The construction engineer estimates the cost of construction, determines the procedures to be followed, and designs the temporary supports for the form work. The construction inspector, a technician, inspects the construction materials and observes the method of placing reinforcing steel and concrete to ensure compliance with plans and specifications. (*California Division of Highways.*)

Application

Refrigeration technician: selects condensers, compressors, and other refrigeration equipment to meet specifications.

Field-service representative: provides liaison between aircraft manufacturer and airlines and military services.



Chemical Research Technician Testing Butyl Rubber

This lab worker is operating the ozone resistance tester which measures the resistance of insulating materials to the deteriorating effects of ozone, which is present where there is high voltage, as in automobile or aircraft ignition systems. His responsibilities include maintaining the equipment, making the observations, and reporting the results. (*Standard Oil Co. of New Jersey.*)

Electrical draftsman: prepares wiring diagrams for installation of electrical equipment.

Sales

Electronic sales technician: sells electronic equipment and components to manufacturers.

Chemical salesman: sells chemicals and related apparatus to dealers and manufacturers.

Electrical power salesman: advises industries on new electric-powered processes and equipment.

Industrial

Motion- and time-study man: gathers data on workers and times operations.

Quality-control technician: applies statistical methods to quality control in manufacturing plants.

Personnel assistant: assists in conducting training, recreation, and safety programs among employees.

While the same number of examples have been given under each of the engineering functions, the greatest number of technicians are actually employed in drafting and in installation, operation, maintenance, inspection, testing, and sales. However, it is true that wherever engineers are employed, there is need for technicians as well. In order to indicate the nature of the work, the duties and responsibilities of two types of technicians will be described in detail.

The Draftsman

The rough sketches and specifications of the engineer are turned into precise and detailed drawings by the draftsman. Using special drafting pencils, triangles, T squares, protractors, compasses, dividers, scales, and drafting machines, ideas are translated into standard forms for use in production, construction, and assembly. The draftsman usually starts as a tracer making copies of drawings already prepared. With additional training and experience, a tracer can advance to detailer, junior draftsman, and senior draftsman.

In contrast to the routine work of the tracer, the more experienced draftsman makes calculations of dimensions, area, volume, and weight of component parts. Using his knowledge of mathematics, physics, and engineering practice, he makes decisions on strength and other properties of components and selects types of threads, bolts, gear ratios, and other standard machine elements. Using his specialized knowledge of drawing techniques, he portrays objects correctly, clearly, and artistically.

The Electronic Technician

The electronic technician needs training in electronic theory and practice, electrical circuits, and mathematics in addition to skill in handling instruments and equipment and manual dexterity with small tools. He may find employment in an electronic development laboratory, in the electronic manufacturing industry, or in one of the applications of electronics.

In a laboratory he constructs, tests, and operates experimental apparatus. Working with a development engineer, he may follow detailed instructions or he may be given an opportunity to devise circuits, select components, and determine methods of construction. He is called upon to test and evaluate equipment using instruments such as voltmeters, ammeters, ohmmeters, bridges, oscilloscopes, and standard signal generators.

In manufacturing, the electronic technician supervises assembly and inspection or performs production testing. He installs and maintains electronic production equipment such as welding timers, radio-frequency heaters, electric-eye inspection devices, and other industrial electronic units.

Radio, television, facsimile, telephony, radar, sonar, and navigational aids are some of the applications of electronics which offer employment opportunities to the technician. In these fields he may use his specialized training and skill in installing, operating, or maintaining complex equipment. While radio and television employ the majority of people in the great electronics field, the industrial and commercial applications are becoming increasingly important. Application of electronics to achieve greater production, faster communication, more precise measurements, and more sensitive control has resulted in an expanded demand for qualified technicians.

Technician Training

The training for technician positions differs in content and purpose from that of the vocational school on one hand and the engineering college on the other. Training programs vary greatly, but they tend to have the following common characteristics:

1. The training is essentially technological in nature, based on principles of science applied quantitatively, emphasizing reasoning processes rather than "rules of thumb."
2. The preparation is for activities within the field of engineering, but it is specialized and more limited in scope than that for professional engineering.
3. The programs are shorter, more intensive, and less theoretical than engineering curricula with more emphasis on industrial practice.

Young persons who wish specific preparation for careers as technicians can obtain training in technical institutes, junior colleges, extension divisions of colleges and universities, correspondence schools, and special programs operated by industrial concerns. These schools offer 1, 2, or 3 years of training beyond the high school level, 2 years being the most common period. A great variety of curricula is available, but nearly all offer work in mathematics, science, and engineering as applied to a particular field. In addition there is intensive training in the use of the instruments and tools used in the specific activity.

Earnings

The technician category includes so many different positions in such a variety of industries that no general statement can be made regarding earnings. Some surveys indicate that the graduate of a 2-year technical institute in his first job receives approximately the same salary as the 4-year graduate in engineering. In some cases his more specialized training earns a slightly higher salary. The fact that he begins earning 2 years earlier is a big economic advantage.

On the other side of the ledger is the fact that his salary trend will level off sooner than that of the engineer. This is not necessarily so for the well-prepared technician with ambition who continues to improve himself through experience and further training. There is no salary limit on the technically trained individual with initiative and the ability to shoulder responsibility.

SCIENTISTS

It is difficult to draw a sharp line between chemistry and physics or between physics and mathematics or between chemistry and geology. All the physical sciences are interrelated and interdependent. In many cases it is difficult to differentiate between engineers and the scientist coworkers; this is especially true in the research and development functions.

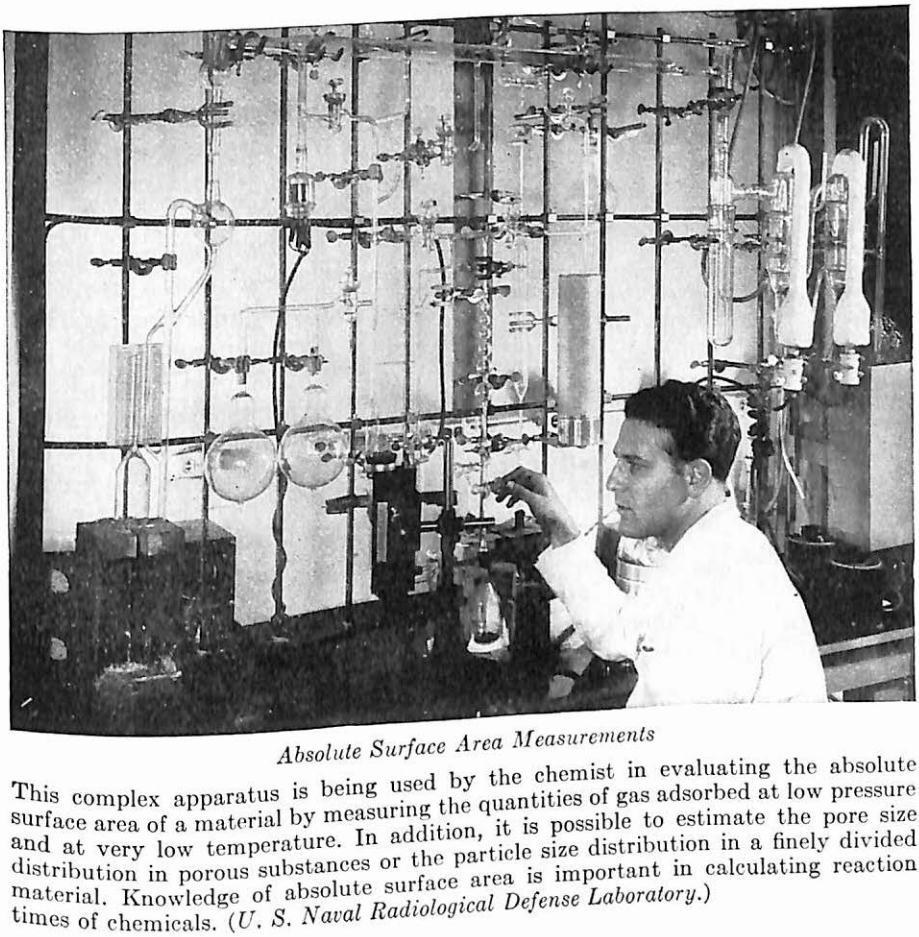
Perhaps the most important distinction lies in the fact that the scientist is usually a specialist assigned a rather limited responsibility and intensely active in a relatively well-defined field. In contrast, the engineer frequently carries over-all responsibility for a project and therefore must be concerned with the application of various sciences to a practical purpose, the methods and machines for accomplishing that purpose, the efficient organization of men, and the all-important item of cost. The choice between a career in science and a career in engineering probably should be based on your aptitudes and interests as related to these activities.

The importance of the physical scientist has increased greatly in the last 15 years. The demands of World War II for the technical advances necessary for national preservation brought the scientist into the spotlight. The uneasy peace which followed has made us aware of health, economic, and technical problems throughout the world as well as the more publicized political problems. Perhaps the contributions of the scientist in relieving sickness and misery and raising the standard of living for the less fortunate members of our human family will make the job of the social scientist easier and the work of the military man less necessary. Certainly the outlook for the future is favorable in terms of opportunity for service as well as employment possibilities.

The great majority of physical scientists are engaged in research, development, analysis and testing, and teaching. They are employed in private industry, government agencies, and educational institutions. In comparison with the 600,000 engineers in this country, there are approximately 100,000 chemists, 25,000 earth scientists, 20,000 physicists, 15,000 mathematicians, and smaller numbers of meteorologists and astronomers.

The Chemist

Of all the physical scientists, the chemist has made the greatest direct contribution to American industry. After becoming firmly established as an industrial partner at the turn of the century, the field of chemistry grew rapidly. There was a spectacular expansion during the 1940's and further growth since 1950. Three-fourths of all chemists are employed in private industry, the majority in manufacturing industries. Advances in



Absolute Surface Area Measurements

This complex apparatus is being used by the chemist in evaluating the absolute surface area of a material by measuring the quantities of gas adsorbed at low pressure and at very low temperature. In addition, it is possible to estimate the pore size distribution in porous substances or the particle size distribution in a finely divided material. Knowledge of absolute surface area is important in calculating reaction times of chemicals. (*U. S. Naval Radiological Defense Laboratory.*)

chemistry have influenced all branches of engineering, completely redirected some of our basic industries, and made possible tremendous strides in medicine.

As a group, chemists are young and highly trained. Two-thirds are under 40 years of age, and a high proportion have advanced training beyond the bachelor's degree, approximately 15 per cent holding the doctor's degree as compared with 4 per cent of engineers. Chemists usually specialize, with organic (46 per cent), analytical (13 per cent), inorganic (9 per cent), and physical (8 per cent) chemistry being the most popular.

The work of the research chemist is quite similar to *research* in engineering. Working in a college, industrial, or government laboratory, the research chemist is endeavoring to push back the frontier of knowledge about matter, its composition and changes in composition. He seeks to find out *what* happens, *why* it happens, and *how* it happens. He devises experiments and tests to unlock nature's secrets. What is the true nature of the complex protein molecule? Why is one molecule strong and another weak? How do plants carry on the remarkable process of photosynthesis?

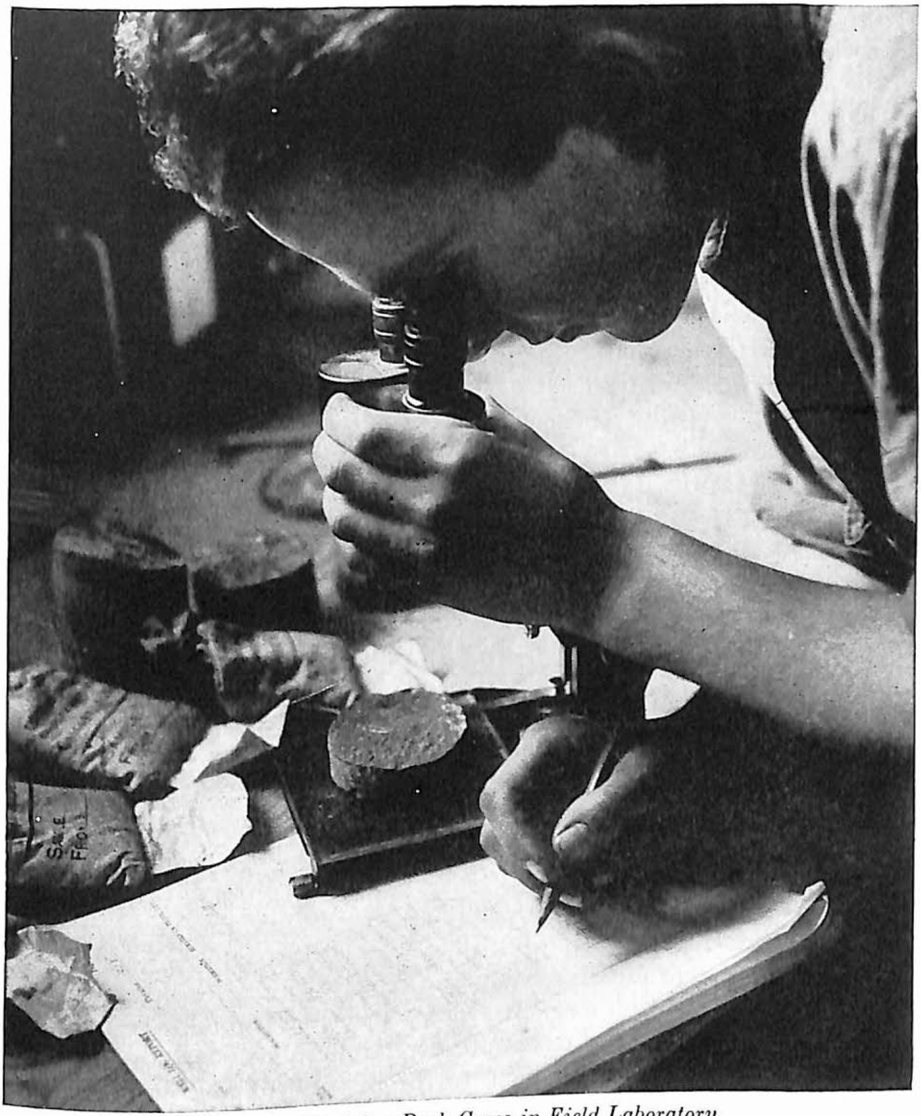
Behind new fuels, paints, foods, textiles, and paper and rubber products are the contributions of chemists assisting in *development*. Here the questions faced by the chemist have a practical slant. How can the molecular structure of a hydrocarbon atom be modified to give a smoother burning fuel? What process can be used to make nylon crease-resistant? What can be done to maintain the vitamin content of preserved food?

Much of the progress in chemistry and engineering is based on facts and data obtained and recorded by specialists in *analysis* and *testing*. Analytical chemists employ apparatus such as the spectrophotometer which in a few seconds will determine the composition of an unknown complex substance or sensitive devices which will indicate the presence of a few molecules of poisonous gases. The chemical behavior of materials exposed to heat, light, moisture, or active chemicals can be determined under carefully controlled conditions.

Frequently the college or university professor combines *teaching* and research, since the functions of a university include communicating our present knowledge and also adding to the store of knowledge. With the rapid growth of engineering and the sciences, there is an increased demand for science and mathematics teachers at all levels of instruction from the high school to the university graduate school.

The Geologist

The earth sciences are generally grouped under geography, geology, and geophysics. *Geographers* are concerned with political, cultural, economic, and historical aspects of the subject and have little in common with



Geologist Studying Rock Cores in Field Laboratory

Minerals and petroleum are not deposited according to any known law. The primary job of the geologist is to search for the geological conditions under which oil might exist or where minerals might be found. He obtains information in the field—from rock outcroppings on the surface or from rock cores brought up by special drilling bits—and interprets it using his knowledge of geological formations. Development of practically all oil fields and mineral deposits is guided by geological work. (*Standard Oil Co. of New Jersey.*)

the engineer. *Geologists* study the earth's structure and history as revealed by rock formations, whereas *geophysicists* employ various physical sciences in the study of the earth and its atmosphere and oceans.

Geologists work in exploration, research, consulting, and teaching. A geologist usually spends a large portion of his time in field work—surveying, taking notes, making maps, and collecting specimens. He studies rocks, soils, minerals, fossils, and rock layers. Some specimens are examined in more detail in a laboratory. The petroleum geologist, for example, applies modern techniques and scientific instruments to locate oil reserves, whereas in the past oil was sought by hit-or-miss methods. Once a promising subsurface structure is located, the geologist works with the engineer in deciding where to drill. Well cores brought up by special drills are analyzed to decide whether or not to continue drilling.

The great majority (70 per cent) of American geologists work for private industries, primarily the petroleum and mining industries. Colleges and universities employ a large number (12 per cent) in teaching and research, and Federal and state agencies use geologists (13 per cent) in the field and in laboratories and offices throughout this country and in Allied countries.

The Geophysicist

Originally geophysicists were concerned with such phenomena as earthquakes, volcanoes, and the force of gravity. Modern geophysical science includes hydrology, meteorology, geodesy, terrestrial magnetism and electricity, volcanology, oceanography, seismology, and exploration geophysics. In each of these fields scientists are engaged in research, consulting, and teaching.

A field closely associated with engineering activities is exploration or prospecting geophysics. The geophysicist organizes and conducts field parties in the search for promising sites for oil drilling. In seismic prospecting, the seismograph measures the propagation through the earth of sound waves created by a dynamite explosion. Waves striking various rock formations are reflected back to the instrument and provide data from which the geophysicist determines the nature of underground formations.

Opportunities for careers in the earth sciences will continue to increase because of the necessity for taking full advantage of our natural resources. At the present time there is emphasis on increasing our supplies of petroleum, uranium, and other strategic materials. Actually we know very little about the earth's crust, not to mention the earth's interior, upper atmosphere, and ocean depths. The search for hidden resources and the efficient development of those found offer challenges to the young scientist.

The Physicist

The events of the last 15 years have brought the physicist to the attention of every citizen and made the names of Newton, Hertz, Einstein, and Oppenheimer familiar to us all. From the university laboratory, the physicist has moved into government and industry on an unprecedented scale. Probably this trend will continue, and the physicist will make an ever-increasing contribution to our civilian economy as well as our defense activities.

Study of the Ejection of Electrons from Solid Bodies

The work of the physicist in learning more about fundamental physical processes provides knowledge which can be applied by engineers. In this apparatus a beam of positively charged particles is focused on a solid material and the electrons knocked loose by the bombardment are counted and checked for speed. Knowledge gained in such experimental studies is expected to contribute to the design of better electronic tubes. (*Bell Telephone Laboratories.*)

The level of training of physicists is very high; one survey showed 45 per cent of a select group to hold doctor's degrees and 27 per cent to have master's degrees. The largest groups of physicists are those concerned with electronics, nuclear energy, and optics; the minor subdivisions include atomic and molecular, quantum theory, solid-state physics and mechanics, heat, and acoustics. In each of these fields, physicists are engaged in research, development, consulting, and teaching.

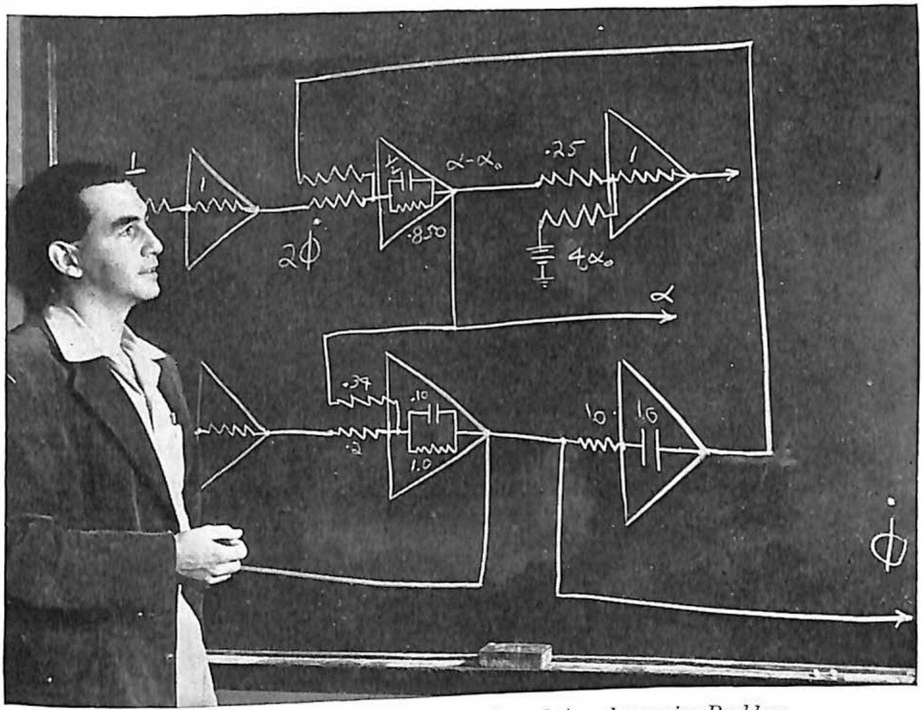
Research in electronics has contributed to the development of radio, radar, television, the electron microscope, and many other applications of vacuum and gas-filled tubes. Nuclear physicists are investigating the structure and properties of the nucleus of the atom by accelerating particles to tremendous energy levels in cyclotrons and bevatrons and using them to bombard nuclei. Optical science is concerned with the study of light sources, propagation, and effects; the efficient fluorescent lamp and the superlatively precise optical instruments are illustrative of the practical results of the physicist's basic research.

In 1955 more physicists were employed in private industry than at any previous time. Although much of the expenditure for research and development was financed by the Federal government, over half came from private industry itself, and the place of the physicist in industry is well-established. University laboratories have always been leaders in basic research and are now undertaking an increasing amount of applied research and development as well. In government, two major areas of employment for physicists are aeronautics and nuclear energy. The development of aircraft for supersonic speed and of nuclear-energy-powered ships and submarines requires the solution of countless complex problems involving basic physics. Certainly here is a field of opportunity.

The Mathematician

It used to be that the main employment opportunity for mathematicians was in teaching, with few positions available elsewhere. While teaching positions continue to be important numerically, the beginning mathematics student can also consider attractive careers in applied statistics, mathematical research in industry or government laboratories, or actuarial work.

Mathematical statistics has become an important field in this country in the last 30 years. The statistical problems which arise in scientific research, in business and industry, in economic investigations, and in government work are dealt with by two types of mathematicians. Mathematical statisticians are concerned with the general mathematical theory of data and observations, probability theory, and advanced statistical concepts. The applied statistician, on the other hand, is skilled in the application of statistical methods to a certain field. He may be an expert in some field of applied science—a biologist or an engineer—who adapts statistical methods to his own situation. Examples of applications of statistics include industrial quality control, biological research, analysis of government statistics, market research, and psychological testing.



Schematic Operational Representation of Aerodynamics Problem

The development of electronic computers permits wider application of mathematical analysis to complex problems. Here the mathematician is proposing an arrangement which will simulate a complicated aerodynamics problem and permit its solution by means of an electronic analog computer. Work is also being carried on in the development of new methods of mathematical analysis for the solution of problems that cannot be solved by standard procedures. When analytical approaches can be made to engineering development problems, expensive experimentation can be reduced or often eliminated. (*U. S. Naval Ordnance Test Station.*)

While the use of mathematics in industry is extensive, the number of mathematicians is small because most of the mathematics is within the level of engineering training. The industrial mathematician acts as a consultant helping engineers to formulate and solve the more difficult problems. He helps to design experiments and analyzes the results. Since he works with engineers, he must be able to speak their language and should have a background in engineering sciences. Some industrial mathematicians spend most of their time solving problems resulting from daily consultations with technical men. Others are engaged in creative research aimed at evolving new mathematical methods for solving problems.

The mathematical activities in government cover a very wide range so that a great variety of opportunities exist; the actual work, however, is similar to that of the mathematician in industry. The levels of activity range from the computer, for which the bachelor of science degree is adequate training, to the highest level of mathematical research, for which the Ph.D. is required. Operations research, a new field, is concerned with providing a scientific basis for making decisions on operations and management problems which are not ordinarily subject to mathematical treatment. Mathematicians in this field are seeking methods of solving problems in strategy, logistics, and military operations.

The actuary of a life insurance company is responsible for calculating the premium rates his company charges and for preparing the tables of death rates which serve as the basis of insurance calculations. He takes into account the effects of various hazards and risks and sets dividend rates. This work requires a combination of mathematics training and business experience. The rapid growth of group insurance, pension plans, and other forms of social and casualty insurance has brought many theoretical and practical problems for which the mathematician is needed.

Training of the Scientist

While the accepted training for most engineering positions is the B.S. degree, most responsible scientific positions require graduate work, and for many the Ph.D. degree is specified. Since the scientist is working at the frontier of learning, he must bring his own knowledge up to the limits in his particular field. The best place to obtain this training is in the graduate school of a university where the faculty are actively engaged in fundamental research along with their teaching.

The difference between undergraduate training in practical science and advanced theoretical research can be illustrated by citing mathematics as an example. The mathematics studied by the engineer, geologist, chemist, and physicist is largely concerned with problem solving—complex problems and powerful concepts but still directed to practical purposes. In contrast the research mathematician is concerned with mathematical logic and abstract ideas which are not directly related to problem solving. In all fields, the research scientist is far out ahead of technical progress, and his training must emphasize the most advanced concepts and techniques.

There are many opportunities for scientists with only the bachelor's degree or with one or two years of graduate work. For field work in the earth sciences, for applied statistics, for chemical analysis and testing, the doctor's degree is not required. In most of these occupations the skill in application of science which comes with experience may be more valuable than additional graduate work. However, the trend is toward higher and higher educational requirements.

Personal Qualifications

The work of the scientist is reflected in the qualifications required. To obtain the necessary training requires an extremely high level of intelligence and great mental capacity. To make a contribution requires initiative, creative ability, and experimental ingenuity. The successful researcher is more frequently a brilliant thinker than a careful, methodical workman.

On the other hand, the scientist is usually a specialist who is not required to carry the burden of responsibility given to the engineer. There is not the same necessity for the scientist to be able to direct the work of other men, nor need he be greatly concerned with economic factors in his work. His goal is the truth, and all other considerations are secondary.

Earnings

In general the physical scientist and the engineer fare equally well in starting positions with the same educational qualifications. The median incomes of all engineers, however, tend to be higher because a larger percentage of scientists are employed by relatively low-paying educational institutions. The opportunities for engineers to move into high-salaried management positions give them an advantage at the upper end of the salary range. Some industries are beginning to recognize the value of the unique contributions of the scientist by setting up salary schedules which provide the same compensation for the specialist in his laboratory as for the manager with broad responsibilities.

SUMMARY

The technician, the engineer, and the scientist form an efficient team which is responsible for our technical progress. There are many similarities between the members of the team: They are all interested in things of the physical world; they all require ability in logical, quantitative reasoning; comparable salaries, to start at least, are available to qualified men in all three categories.

The work done, the personal qualifications, and the training required vary greatly. The technician specializes in a single activity, and usually one or two years of intensive post-high school training is adequate; skill in applying elementary science to technical problems and manipulating instruments and tools is required for success. The work of the engineer extends through a wide range of functions from operation and maintenance at one technical extreme to development and research at the other. The scientist works at the frontier of knowledge seeking to make known the unknown, and he also works with the engineer in the more scientific functions. His work requires a high level of intelligence, skill in creative thinking, and advanced training in theoretical science.

As you plan your career, compare your interests and aptitudes with those discussed in this section. Does your liking for manipulation of apparatus indicate that you would be happier in a technician's job? Or do your interests and mental abilities point toward advanced training and a career in pure science? Or does one of the functions of engineering line up with your own qualifications? The choice is yours to make, and now is the time to make the choice.

ASSIGNMENTS

7-1. Select a common article, and familiarize yourself with various phases of its manufacture and use. Describe, in a brief report, the work which would be done in connection with the selected article by a scientist, an engineer, and a technician. Devote a short paragraph to each.

7-2. List 10 specific contributions made by scientists to the modern automobile.

7-3. Name five positions which could be held by technicians in a refrigerator manufacturing plant, and indicate, briefly, the specific work done in each.

7-4. Compare the monthly salaries earned in your community (in a single industry if possible) by a typical technician, engineer, and scientist. Obtain data for 27-year-olds (the scientist would be just starting work) and for 40-year-olds. Information may be obtained from personal interviews, employment managers, employment agencies, or publications. Analyze your findings, and draw a brief conclusion.

8

ECONOMIC STATUS OF THE ENGINEER

Is engineering an expanding profession? Where do most engineers work? For whom do they work? In which branches and functions are the largest numbers of engineers employed? How much do engineers earn, and how is their income affected by experience and education? Briefly, what are the facts about engineering?

The purpose of this chapter is to provide a statistical picture of the engineering profession as revealed by the numerous surveys which have been made by various agencies in the last 10 years. Unfortunately no one agency has ever studied all aspects of the entire profession at any one time. To bring out the picture, we shall have to piece together bits of information obtained from different sources having slightly different viewpoints.

Only those aspects of engineering which are of interest to beginning students will be considered here; a more complete picture can be obtained from a detailed study of the references listed at the end of the chapter and designated by numbers in brackets—[ ]—when referred to in the text and tables. The growth of engineering; the distribution within the profession by branch, function, education, and type of employer; the earnings of engineers as influenced by various factors; and the outlook for future employment in engineering have been selected as topics for discussion.

GROWTH OF THE ENGINEERING PROFESSION

Engineering is a dynamic activity which is growing at an ever-increasing rate. As indicated by Bureau of the Census data [1] in Fig. 8-1, the total number of engineers in 1940 was 10 times greater than in 1890 although the total number of workers in all fields only doubled during that 50-year period. Since 1940 the total number of engineers has doubled again, the Engineers Joint Council [2] estimating over 460,000 in 1953. Other estimates are even higher [3].

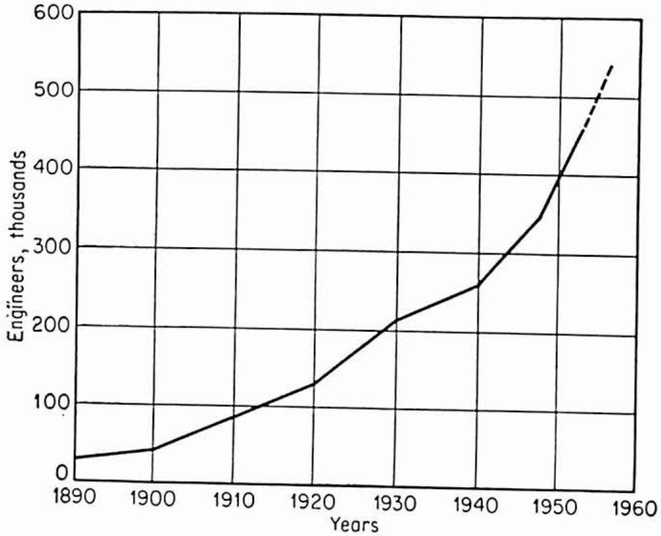


FIG. 8-1. Growth of the engineering profession.

Industrial Workers per Engineer

The fact that engineers are becoming more important proportionately is indicated by the corresponding decrease in the number of industrial workers per engineer. Five basic industries—manufacturing, construction, transportation, public utilities, and mining—employ three-fourths of all engineers (see Table 8). In these industries the number of workers increased nearly threefold, while the total of all workers only doubled. Instead of merely paralleling the growth of industry, engineering increased more than three times as fast. Figure 8-2 shows that the number

TABLE 8. DISTRIBUTION OF THE ENGINEERING PROFESSION IN 1946 BY MAJOR INDUSTRY FIELD [4]

Number reporting		37,325
Manufacturing	41.8%	
Construction	18.4	
Utilities	11.1	
Personal services	9.4	
Mining	6.1	
Communication	4.2	
Transportation	2.2	
Other industries	6.3	
Unemployed	0.5	
Total	100.0%	

of industrial workers per engineer decreased from 290 in 1890 to 78 in 1940 and to 60 in 1950. It has continued to decrease and probably would be even lower if it were not for the present shortage of engineers.

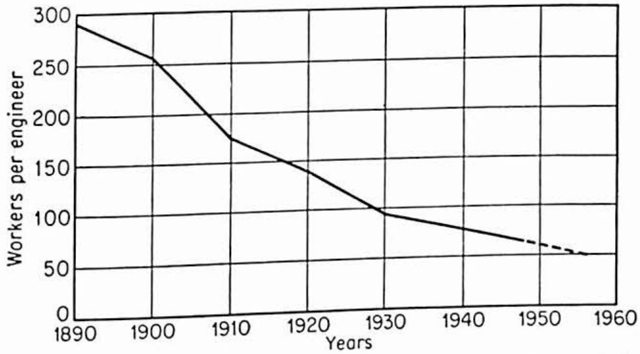


FIG. 8-2. Number of industrial workers per engineer in five basic industries. [1]

Geographical Distribution

As the profession has grown, the geographical distribution has remained relatively unchanged. Engineering activity, along with industrial and commercial activity, tends to be concentrated in population centers.

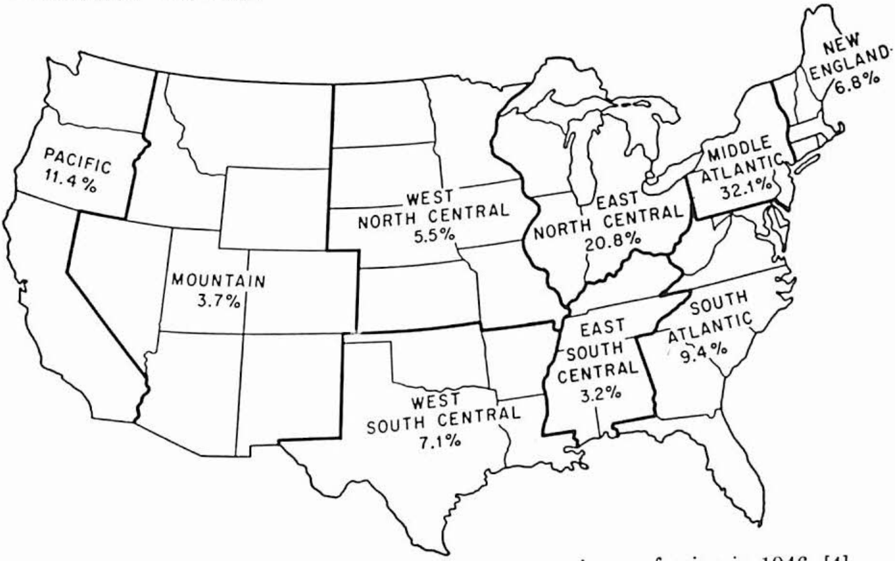


FIG. 8-3. Geographical distribution of the engineering profession in 1946. [4]

Exceptions include mining in the remote areas of the mountain division and petroleum engineering in Texas. In general, however, the larger numbers of engineers are employed in populous regions or heavy industrial states such as New York, Pennsylvania, California, and Ohio. Figure 8-3 illustrates the geographical distribution of members of six major engineering societies in 1946. Comparisons with the corresponding data for 1943 and 1939 indicate no significant geographical shifts.

COMPOSITION OF THE ENGINEERING PROFESSION

The available reports on the engineering profession vary considerably because of the variation in composition of the groups surveyed. For our purposes, perhaps the most useful study was that made in 1949–1950 by the Engineers Joint Council [5] for the Department of Defense. The survey included 55,000 engineers holding full professional membership in 13 selected engineering societies; student, junior, and associate members were excluded. The total represents less than one-eighth of the entire profession but more than half of all engineering society members of full grade. In this section, this group will be considered to be representative of the engineering profession.

Distribution by Branch

As indicated in Table 9, mechanical engineering is the largest branch with 27 per cent of the total, and civil engineering is next largest with nearly 25 per cent. In comparison with other surveys [1, 4], the figures given here for electrical and chemical are low and those for metallurgical and mining are high. Possibly this is owing to the fact that society membership is more common in some branches. Perhaps 21 per cent in electrical, 9 per cent in chemical, and 7 per cent in metallurgical-mining would be more representative for the entire profession.

TABLE 9. DISTRIBUTION OF ENGINEERS BY BRANCH IN 1949–1950 [5]

Civil		24.6%
Mineral		17.2
Metallurgical	8.7	
Mining	3.3	
Petroleum and fuels	4.1	
Ceramic	1.1	
Mechanical		27.0
Power plant	4.3	
Aeronautical	3.8	
Automotive	2.1	
Other mechanical	16.8	
Electrical		14.7
Electrical	11.8	
Electronics	2.9	
Chemical		6.3
Other engineering		8.1
Nonengineering		2.1
Total		100.0%

Distribution by Function

Table 10 indicates that design is the most frequently mentioned function (22.6 per cent), followed by operation (14.7 per cent) and management (12.9 per cent). Note that the 1949–1950 EJC survey of experienced engineers followed a slightly different functional classification from that used in this text. A statement commonly heard is that "50 per cent of all professional engineers are in administrative positions within 15 years after graduation." When engineers classify themselves, there may be some unconscious bias toward what they believe to be more respectable functions. However, the author believes that the EJC data provide the most nearly correct picture of the composition of engineering at present.

TABLE 10. FUNCTION PERFORMED BY ENGINEERS BY BRANCH OF EMPLOYMENT IN 1949–1950 [5]

Function	All branches	Chemical	Civil	Electrical	Mechanical	Min. and metallurgical	Other engrg.	Non-engrg.
Research	7.3%	18.6%	2.0%	5.2%	5.6%	17.3%	7.0%	11.5%
Development	9.0	17.4	2.7	13.2	9.3	12.2	8.0	5.5
Design	22.6	11.0	28.2	27.2	34.0	2.6	10.1	7.1
Construction	8.9	1.4	26.5	5.2	3.6	1.1	2.7	1.2
Production	5.2	14.8	0.4	2.0	3.6	14.3	8.3	1.0
Operation	14.7	7.6	13.9	17.2	10.2	20.4	20.4	26.3
Procure. and sales	6.0	5.2	1.8	7.8	9.8	3.3	7.5	2.2
Management	12.9	11.6	11.7	10.3	10.7	11.6	23.2	23.1
Teaching	4.9	4.9	4.4	6.0	5.6	4.2	2.6	10.8
Testing	3.1	3.6	1.2	1.7	3.7	8.6	2.2	1.5
Other	5.4	3.9	7.2	4.2	3.9	4.4	8.0	9.8
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Total No. reporting	52,662	3,998	12,986	7,784	14,046	6,296	6,438	1,114

Note that the numerical importance of the different functions varies from branch to branch. More chemical engineers are engaged in research than in any other function, while the greatest percentage of mechanical engineers is in design. What correlation would you expect to find between function and level of education?

Distribution by Educational Level

Engineering is not a "closed" profession; one out of five engineers has not completed formal training leading to a college degree (see Table 11). The accepted level of training for the bulk of engineering positions is the bachelor's degree, and only one out of five engineers has completed an advanced degree. However, nearly every year since World War II has seen an increase in graduate enrollment in engineering, and it can be expected that the percentage of engineers holding advanced degrees will rise.

As would be expected, advanced degrees are most common in research, development, and teaching. The lack of a college degree appears to be less of a handicap in such functions as construction, design, procurement, and sales. The high percentage of engineers without degrees in design is related to the fact that 27.6 per cent of the mechanical engineers surveyed had not finished college, and probably many of these moved into design engineering from technician positions as draftsmen.

TABLE 11. LEVEL OF EDUCATION OF ENGINEERS IN 1949–1950 [5]

Education	Number		Per cent	
Doctor's degree		1,987		3.7
Engineering	1,132		2.1	
Nonengineering	855		1.6	
Master's degree		8,759		16.5
Engineering	7,716		14.5	
Nonengineering	1,043		2.0	
Bachelor's degree		31,724		59.4
Some graduate credit	3,591		6.7	
No graduate credit:				
Engineering	26,718		50.1	
Nonengineering	1,415		2.6	
No degree		10,909		20.4
Some college credit	7,383		13.8	
No college credit	3,526		6.6	
Total reporting		53,379		100.0

EARNINGS OF ENGINEERS

Engineering is one of the better paid professions, ranking above the ministry and teaching, about even with architecture, and below medicine and law. In comparison with other sciences, engineers with similar training in comparable positions do well.

Comparison with Other Sciences

In 1948 a survey [6] was made of 42,000 outstanding scientists whose primary interest was research; the group constituted a roster of key persons representing all the natural sciences. While the actual salary figures are no longer valid, the relative earnings of the various groups as shown in Table 14 are interesting. Of those in this group possessing Ph.D. degrees and working in private industry, engineers received the highest salaries, 13 per cent higher than the median; psychologists were second; and earth scientists third. The report of the survey indicated that engineers led in salary among those Ph.D.'s employed in educational institutions and government service also.

TABLE 12. LEVEL OF EDUCATION OF ENGINEERS BY BRANCH OF EMPLOYMENT IN 1949–1950 [5]

Branch	Doctor's	Master's	Bachelor's	No degree	Total
Chemical	14.1%	21.7%	55.7%	8.8%	100.0%
Civil	1.1	15.6	61.7	21.6	100.0
Electrical	3.5	7.9	61.4	17.2	100.0
Mechanical	1.9	14.6	55.9	27.6	100.0
Mining and Metallurgy	4.3	16.5	61.9	17.3	100.0
Other engrg	4.3	15.7	63.1	16.9	100.0
Nonengrg	13.7	24.1	48.3	13.9	100.0
All branches	3.8	16.4	59.5	20.3	100.0

TABLE 13. LEVEL OF EDUCATION OF ENGINEERS BY FUNCTION PERFORMED IN 1949–1950 [5]

Function	Doctor's	Master's	Bachelor's	No degree	Total
Research	14.9%	25.9%	51.2%	8.0%	100.0%
Development	4.7	17.5	63.0	14.0	100.0
Design	1.0	12.8	61.5	24.7	100.0
Construction	0.3	9.0	61.9	28.8	100.0
Production	1.7	14.1	65.0	19.2	100.0
Operation	1.0	12.8	63.5	22.7	100.0
Procure. and sales	0.6	8.9	66.2	24.3	100.0
Management	2.8	17.0	60.8	19.4	100.0
Teaching	21.9	52.1	23.9	2.1	100.0
Testing	1.3	14.4	64.1	20.2	100.0
Other	3.7	17.1	56.6	22.6	100.0
All functions	3.7	16.4	59.6	20.3	100.0

Starting salaries are good at present (see Figure 8-4), considering the limited amount of training and experience required, and seem to be keeping pace with increases in other technical and scientific occupations. The salary earned by an engineer depends upon his experience, his education, the function he performs, the employer for whom he works, and, most important of all, his own personal qualifications.

Experience

To illustrate the effect of experience on earnings consider Fig. 8-5, which is based on data obtained in 1953 [2] from 295 companies employing *upper quartile* is the income exceeded by one out of four. The actual values no longer apply, but the shape of the curve is typical of the results of many similar surveys.

Income continues to rise with experience over a long period of time. The continuous rise indicates the value of judgment, developed through experience, in an engineer's professional worth and compensation. It also indicates that opportunities for promotion and increased income are open to engineers.

TABLE 14. 1948 EARNINGS OF A SELECTED GROUP OF AMERICAN MEN OF SCIENCE [6]

		Holders of Ph.D. degrees		
			Employed in private industry	
Field of specialization	Total scientists reporting	% of total	Median salary	% of median of all fields
All fields	41,737	62.4	$7,070	100
Engineering	4,906	33.3	8,000	113
Psychology	1,589	93.8	7,940	112
Earth sciences	2,089	63.7	7,780	110
Physics and electronics	3,439	70.7	7,350	104
Mathematics and statistics	1,930	83.2	7,350	104
Chemistry	10,625	78.4	6,880	97
Fields related to medicine	2,664	46.7	6,850	97
Agriculture	2,427	55.9	6,670	94
Biology	5,819	75.9	6,250	88
Other sciences	3,391	59.3		

Income tends to rise most rapidly at first and less rapidly at the greater experience levels. Before World War II, the average engineer with 20 years of experience received approximately three times as much as the average new graduate [4]. Recent studies [7] indicate that starting salaries have increased more rapidly than those paid to experienced men, and the median income at the 20-year experience level is only about twice that of the newcomer. This has been due in part to the shortage of engineers and competition in hiring new men.

It is not clear whether this is a grossly inequitable situation which should be corrected immediately or it correctly evaluates the modern training of the recent graduate which helps him to cope with the problems facing engineers today and partially offsets his lack of experience. If the latter viewpoint is true, there is a good lesson here regarding the necessity for engineers to continue their education long after graduation.

65,000 engineers out of a total of 2½ million employees. This graph does not represent the earnings of an individual during his career; instead it is a picture of the *median* incomes of groups of different engineers whose experience ranged from 1 to 42 years.

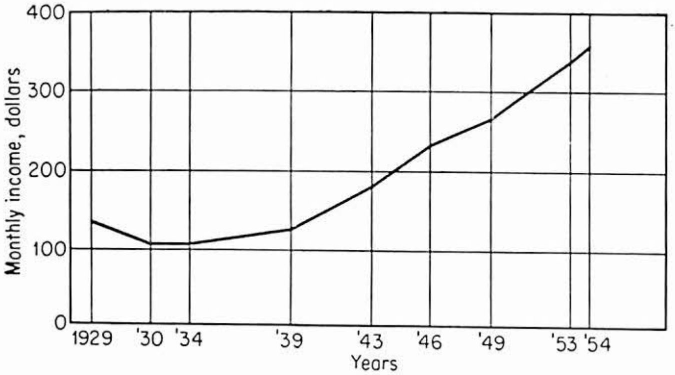


FIG. 8-4. Starting salaries for engineers over a 25-year period. [1, 2, 4, 8]

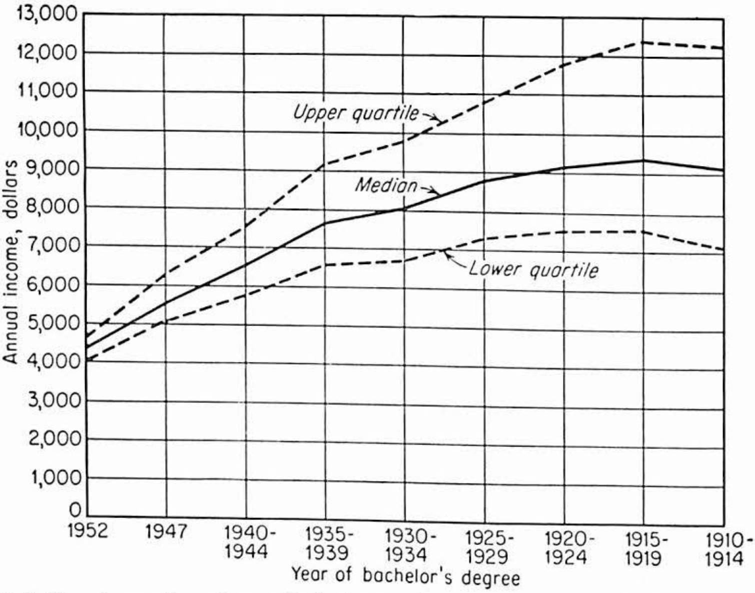


FIG. 8-5. Earnings of engineers in industry by year of entry into the profession.

The median income of $5,617 for the 1947 entrants means that 50 per cent of those surveyed earned more than $5,617 and 50 per cent earned less. The median is used because it is affected less by extremely high values than is the average, or *mean*. The *lower quartile* (or twenty-fifth percentile) is the income exceeded by three out of four of those reporting, and the

Education

The effect of level of education on earnings of experienced professional engineers can be seen by referring again to the 1949–1950 EJC survey [5]. Figure 8-6 shows that the median income of men holding the doctor's degree was considerably higher (19 per cent at the 45–49-year level) than that of men with bachelor's degrees, and they in turn received higher (9 per cent) incomes than those professional engineers without degrees.

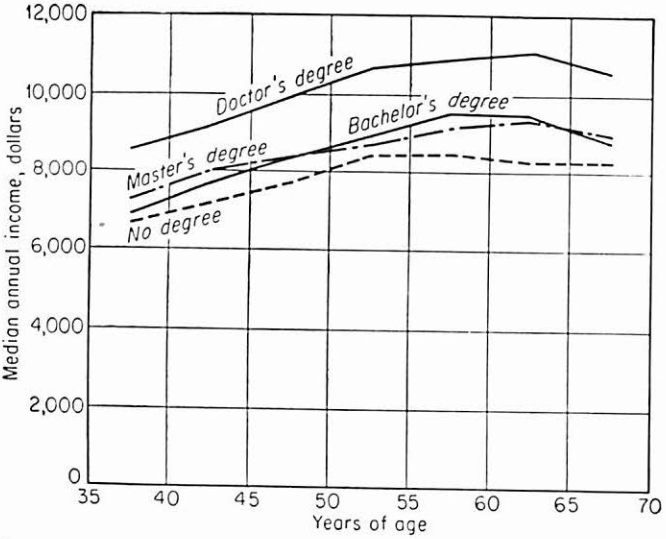


FIG. 8-6. Income of experienced engineers by level of education.

The differences in favor of those with more education were even greater for the top 25 per cent of the engineers surveyed.

It would be expected that the extra compensation paid to holders of doctor's degrees would be greatest in those activities where advanced training is particularly desirable. A 1954 survey [8] of research and development laboratories hiring 50,000 professional scientists showed that over a wide experience range holders of doctor's degrees received median salaries 24 per cent greater than holders of bachelor's degrees.

Function

The 1946 EJC survey [4] indicated that engineers in management receive considerably higher median salaries than those in other functions. Research, with its higher education requirements, comes second, and sales and consulting third. Differences among the remainder are small, but it appears that development, production, operation, design, and construction follow in that order. In general the lower-paid functions include relatively large numbers of engineers without formal training. Engineers engaged in inspection, testing, and drafting (more properly, technician functions) receive the lowest salaries, and the 1946 survey indicated no salary increase after the 8-year experience level.

Type of Employer

One of the most important factors in determining the earnings of engineers is the type of employer for whom they work. Disregarding other factors such as experience and education, the 1949–1950 EJC report [5] indicated that taking salaries earned in private industry as a reference, employers (or owners of businesses) earn 75 per cent more, independent consultants earn 27 per cent more, engineering teachers earn 15 per cent less, and government engineers earn 22 per cent less. A similar picture is presented by the data in Fig. 8-7 taken from a 1952 survey [9] of 12,000 members of the National Society for Professional Engineers.

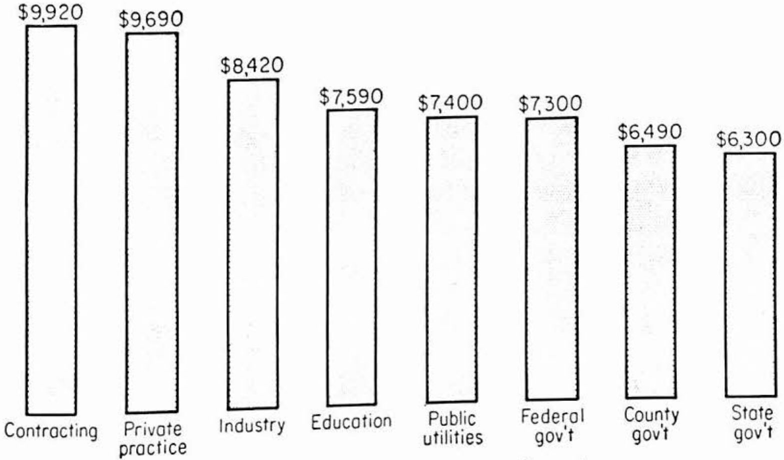


FIG. 8-7. Annual income by type of employer.

Individual Qualifications

Engineering earnings vary with experience, education, function, and type of employer. Apparently an engineer can improve his earning power by gaining more experience, completing a doctor's degree, getting into management, or starting his own business. But this is not necessarily true, because there are inexperienced men earning more than older men, there are engineers who never went to college earning more than Ph.D.'s, there are engineers with bachelor's degrees in government service earning more than Ph.D.'s in research in private industry. The most important factor of all, and one which hasn't been taken into consideration yet, is the man's own personal qualifications.

Referring back to Fig. 8-5, in 1953 the men at the upper quartile who graduated in 1942 were making nearly as much as the median of those who graduated 5 years earlier and more than those at the lower quartile of any graduating class. The gap increases with length of service; in comparing the figures for those graduating in the 1910–1914 period, the upper quartile salary is almost twice that of the lower. The difference is still more impressive when top and bottom 10 per cent groups are compared [4].

The survey of senior members of engineering societies on which Fig. 8-5 is based revealed that for the 45–49-year bracket the upper quartile of those without degrees was $10,400 per year whereas for those with Ph.D.'s the median was $10,000 and the lower quartile was only $7,800. A good man without formal engineering training—and it takes a good man to achieve full professional standing without a degree—can earn more than an average man with all the training available.

OUTLOOK FOR EMPLOYMENT

As this is being written, engineering graduates are in great demand, but what about the long-range prospects? While the present employment situation is affected by the existing international tension and the resultant need for building an adequate defense, the future of engineering as a career appears to be good for several reasons.

In the first place, the increased importance of engineers and scientists in our technological civilization promises an expanding opportunity. The rapid increase in the ratio of engineers to industrial workers is concrete evidence of this trend, and all indications point to a continuation of the trend. In addition, new developments such as automation and operations research are calling for the use of engineers in the future in activities which do not even exist at the present time.

Second, the number of students entering engineering training is not increasing so rapidly as it should if the number of engineering graduates is to keep up with the demand [3]. According to estimates by the Bureau of Labor Statistics and the Engineering Manpower Commission, approximately 40,000 new engineers per year are needed in our combined civilian and military economy. In 1950, 42,000 engineers did receive bachelor's degrees, but since then the average number of engineering graduates has been only 26,000 per year. Even if the fraction of college freshmen selecting engineering continues at its present high rate of 10 per cent, it appears that the number of graduates will not reach 40,000 per year until 1963, and by that time a large deficit may have been built up.

CONCLUSION

Engineering is a dynamic profession which is growing rapidly in numbers and importance; its continued growth is a key factor in the development of our technological society. Engineers tend, in general, to be located in heavily populated and industrialized areas, although exceptions are found in mining, petroleum, and, to some extent, civil engineering.

Three-quarters of all professional engineers are classified as mechanical, civil, or electrical engineers; the remaining quarter is distributed among chemical, metallurgical, petroleum, mining, and other branches in about that order. The design function accounts for about one-fourth of all engineers, operation one-seventh, and management one-eighth; other functions include smaller fractions. Four-fifths of all engineers are college graduates, one-fifth have at least one year of graduate work, and 1 in 25 holds the doctor's degree.

In comparison with other sciences, engineering salaries are good. Starting salaries are high, and income increases with years of experience over the engineer's professional life. As a group, engineers with advanced degrees earn significantly more than those with bachelor's degrees. Engineers in management, research, consulting, and sales earn more than those in other functions. In general, engineers in business for themselves and acting as independent consultants earn more than those in private industry; those in education and government service earn less. The most important factor in determining income, however, is the engineer's own personal qualifications.

Of course, there is more to a professional career than dollar income, but a similar relationship between top and mediocre men exists in other respects. The top man in any activity will make a much greater contribution than the average man, and his influence and prestige will be many times as great. Some of you who read this are destined to become leaders and are endowed with the necessary talents; others, less blessed in inherent aptitudes, have compensating ambitions and drives which will permit you to become outstanding. The place to start preparing for future achievement is in your college training, which constitutes the subject matter of Part II of this book.

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PART TWO

COLLEGE TRAINING IN ENGINEERING

9

COST OF A COLLEGE EDUCATION

Recently a veteran of the Korean War began thinking about the advisability of going to college. Prior to his induction he had been a journeyman electrician, and during his military service he had received training in operation and maintenance of electronic equipment. He was interested in becoming an electrical engineer, and the provisions of Public Law 550 would make it financially possible.

His success in military schools indicated that he was qualified for engineering study. However, because he was 26 years old and already in a skilled trade, he felt obliged to make a careful economic analysis of the situation. At that time journeymen shop electricians were making \$2.20 per hr, and construction electricians were in demand at \$3.10 per hr. He assumed an average pay of \$2.50 per hr and made the following analysis:

Loss in income:	8 hr/day × 250 days/yr × \$2.50/hr × 4 yr =	\$20,000	
Income tax	\$700/yr × 4 yr =	−2,800	
Net loss in income			\$17,200
College expenses:			
Tuition in public institution	\$100/yr × 4 yr =	\$400	
Books and supplies	\$100/yr × 4 yr =	400	
Total college expense			800
Total cost			\$18,000
Gains:			
G.I. benefits	\$110/mo × 9 mo × 4 yr =	\$3,960	
Summer work	\$250/mo × 2 mo × 4 yr =	2,000	
Total gains			5,960
Net investment			\$12,040

According to his analysis (and there are several places where his reasoning is questionable), his going to college represented an investment of \$12,000. Upon graduation, he would be 30 years old. The average starting salary for electrical engineers was around \$350 per month, whereas he was earning over $400 before he went into the service. What would you have done in his place?

This is a rather unusual situation, but a similar decision must be made by every student as he considers spending 4 years in college. What will a college education cost in time and money? What are the benefits to be expected in return? It is the purpose of this section to provide a basis for answering such questions.

ECONOMIC VALUE OF AN EDUCATION

In 1948 the California State Personnel Board announced two positions described as follows:

Highway traffic signal technician	*Assistant electrical engineer*
DUTIES:	DUTIES:
Supervises and works with a crew in the installation and maintenance of highway traffic signal systems.	Prepares plans, specifications, and estimates for electric power plants and substations and other electrical systems.
ENTRANCE REQUIREMENTS:	ENTRANCE REQUIREMENTS:
Five years of experience in installation and repair of electric control devices and education equivalent to completion of the twelfth grade.	Two years of electrical experience and education equivalent to graduation from college with major work in electrical engineering.

Note that the engineer position required a minimum of 6 years beyond high school while the technician position required only 5. How do you think the monthly salaries for these two positions compared? Surprisingly they were exactly the same.

Experience vs. Education

To indicate how lightly college engineering training is regarded sometimes, for the technician position "Graduation from college with major work in engineering may be substituted for *three* years of the required experience." And for the engineer position "Full-time graduate work in electrical engineering may be substituted for (not more than) one year of the required experience, on the basis of one year of education being equivalent to six months of experience."

Consider the possibility of two boys completing the twelfth grade and starting on electrical careers. One boy goes to college for 4 years and then on for 2 additional years of graduate work. After 1 year of paid experience he becomes eligible for the first step of the Assistant Electrical Engineer range. His relatively "uneducated" friend, however, has been earning for all 7 years and is eligible for the third step of the same salary range. Apparently education cannot be translated directly and automatically into increased income.

Value of Education in Engineering

In the preceding example a technician's job was compared with one in engineering. Since only a limited amount of formal education is required for technician work, it must be expected that additional education would be discounted. To get a better picture of the value of education in engineering, let us refer again to the Engineers Joint Council Study of 1949–1950. The median salaries for experienced engineers with various amounts of education were indicated in Fig. 8-6 on page 144.

To obtain a financial evaluation of education in engineering, let us consider four hypothetical "median" individuals who were 38 years old at the time of the 1949–1950 EJC survey. Man D, with a doctor's degree, earned $8,600 during his thirty-seventh year; M with a master's, B with a bachelor's, and N with no degree earned $7,300, $6,900, and $6,700, respectively. While the financial advantages of more education are obvious *at that stage,* let us study the over-all earnings of the four engineers.

To provide a basis for comparison let us make the following assumptions:

1. The shape of the curve of Fig. 8-5 for *different* age groups at *one time* would apply to an individual over his career if the effects of inflation and other economic changes were eliminated.
2. Man N, after graduation from high school at 18, started to work at $200 per month.
3. Man B graduated from college at 22 and received a starting salary of $267 per month.
4. Man M completed his master's degree at 23 and received a starting salary equal to that of B with 1 year's experience.
5. Man D completed his doctor's degree at 25 and received a starting salary equal to that of M with 2 years' experience.

On the basis of these assumptions, the idealized earning curves were plotted and the annual earnings for the four fictitious engineers tabulated in Table 15.

Twenty years after graduation from high school, the median engineer with a doctor's degree has earned a total of $90,000; the men with master's and bachelor's degrees have earned only $87,100 and $86,300, respectively. However, the man who never went to college but somehow became a professional engineer has earned $98,600! This is not so surprising when it is realized that only men of top ability achieve full recognition as professional engineers without formal education.

Table 15. Annual Earnings of Four Hypothetical Engineers of Different Educational Levels

Age	No degree	Bachelor's degree	Master's degree	Doctor's degree
18	$2,400			
19	2,800			
20	3,200			
21	3,500			
22	3,800	$3,200		
23	4,000	3,700	$3,700	
24	4,300	4,000	4,100	
25	4,500	4,300	4,500	$4,500
26	4,800	4,700	4,800	5,000
27	5,000	4,900	5,200	5,500
28	5,200	5,200	5,500	6,000
29	5,400	5,400	5,800	6,500
30	5,600	5,700	6,000	6,800
31	5,800	5,900	6,200	7,200
32	6,000	6,100	6,400	7,500
33	6,100	6,300	6,600	7,800
34	6,300	6,500	6,800	8,000
35	6,500	6,700	7,000	8,200
36	6,600	6,800	7,200	8,400
37	6,700	6,900	7,300	8,600
Total	$98,600	$86,300	$87,100	$90,000

The True Values of College Education

Education is derived from the word "educe," which means to draw forth, and therefore implies there are inner qualities to be brought out. The greatest contribution which education can make is in leading, drawing out, developing, and broadening an individual's own characteristics. The educated person is qualified for various opportunities for satisfying work which are not available to the man whose abilities have not been developed. In addition the educated man has the knowledge and attitudes which should enable him to progress continually in responsibility and satisfaction.

Opportunity. It was pointed out previously that while engineering is not a closed profession, college training is the generally accepted qualification and the fraction of young engineers without degrees is decreasing steadily. The route to full professional status as evidenced by membership in technical societies and professional registration is much easier for the college graduate.

The major justification for graduate work is not on an economic basis but rather because special preparation is desirable for certain engineering functions. The distribution of engineers by level of education and function performed is indicated in Table 13, which is repeated here for ready reference. Over 40 per cent of those in research have advanced degrees. Nearly 75 per cent of those in teaching have completed graduate work, and the present trend is toward regarding the Ph.D. as the standard requirement for young men planning to enter university teaching. On the other hand, graduate degrees appear to be uncommon among construction and sales engineers. When a student has clearly in mind the type of work he plans to do, he can decide what length of time he can devote profitably to formal education.

TABLE 13 (repeated from p. 141).

Function	Doctor's	Master's	Bachelor's	No degree	Total
Research	14.9%	25.9%	51.2%	8.0%	100.0%
Development	4.7	17.5	63.0	24.0	100.0
Design	1.0	12.8	61.5	24.7	100.0
Construction	0.3	9.0	61.9	28.8	100.0
Production	1.7	14.1	65.0	19.2	100.0
Operation	1.0	12.8	63.5	22.7	100.0
Procure. and sales	0.6	8.9	66.2	24.3	100.0
Management	2.8	17.0	60.8	19.4	100.0
Teaching	21.9	52.1	23.9	2.1	100.0
Testing	1.3	14.4	64.1	20.2	100.0
Other	3.7	17.1	56.6	22.6	100.0
All functions	3.7	16.4	59.6	20.3	100.0

Advancement. There have been various studies which indicate that the college graduate is much more likely to become an officer in an industrial concern than is a nongraduate. There are at least three different factors operating here. In the first place, completion of a college course requires ability and drive, which would also lead to progress in industrial positions. Second, college training provides knowledge and skills which are useful in activities such as engineering or business. The third factor, which may be the most important, is that college training develops tolerance for the opinions of others, respect for the power of knowledge, and logical habits of thought which enable the graduate to carry broader responsibilities than the person whose knowledge is limited to his own experience. In many large companies there is a definite line beyond which the nongraduate cannot pass.

COST OF COLLEGE TRAINING

The cost of providing college training by the college and the cost of obtaining college training by the student involve entirely different factors.

Cost to the College

The tuition charge in 4-year colleges and universities varies from practically nothing to over $1,000 per year. In no case, however, is the tuition charge equal to the full cost of providing college training. Schools always must have other sources of income which provide all or a part of the cost of buildings, equipment, instructional salaries, and operating expenses. Individuals, philanthropic foundations, industrial concerns, and municipal, state, and Federal governments all participate in providing the education which enables young people to make their maximum contribution to society.

Cost to the Student

How much will it cost you to obtain a degree in engineering? In the first place you will be investing 4 years of your time. This is time in which you could be beginning your career, earning a living, and starting your family. Deciding to attend college means postponing, until some time in the future, taking your place in society. It means a loss in opportunity for experience as well as opportunity for income. College training is expensive in terms of time.

It is difficult to make any estimate of the dollar cost of a college education. The out-of-pocket expenses directly chargeable to college training include tuition, books, and supplies. Tuition varies from less than $100 to over $1,000 per year. College textbooks provide a good start toward a personal library and should be kept. Technical books, in particular, should be kept for ready reference because the student is familiar with their contents and terminology. Textbooks, slide rules, drafting instruments, and supplies will total several hundred dollars.

The greatest cost to the student is usually his loss of opportunity to earn. In these days of relatively high wages, a capable high school graduate in a metropolitan area can soon be earning $60 a week. Over 4 school years of 9 months each, this would amount to a gross income of nearly $10,000. No matter how it is figured, a college education is a large financial investment.

CONCLUSIONS

A college education is expensive for the society which provides it and expensive for the student who obtains it. The prospective student should analyze his goals and his qualifications and determine if college training is a justifiable investment for him. If he decides in the affirmative, he should then determine whether to spend 1 or 2 years in preparation for work as a technician, 4 years for the bachelor's degree (5 in some institutions), or more for an advanced degree.

While years of education cannot be directly translated into increased salary, college training does pay off for qualified individuals. Of particular value is the opportunity to do satisfying work in a desirable position. Formal education is the most efficient method of preparing for the engineering profession. College provides learning situations which are designed to develop the individual's abilities to the maximum, encourage tolerance for others and their opinions, and engender a respect for knowledge and an unceasing desire to learn. The person who benefits from his college experience will be eligible for positions of greater and greater responsibility. The person who fails to take advantage of his college opportunities is neglecting his own investment as well as that of his relatives and neighbors.

10

SUGGESTIONS FOR COLLEGE WORK

We have established that a college education represents a great investment in both time and money. If it is not already apparent, it will soon become clear that obtaining an engineering degree requires a great deal of intensive effort—it is hard work. At the beginning of this 4-year effort, the student will be wise to analyze the situation carefully. Questions to be answered include: For whom are you working? What are you trying to accomplish? What are the best methods of accomplishing your objectives?

YOUR EMPLOYER

The engineering student carrying a typical load of 18 units or credit hours must work approximately 54 hr per week. For whom are you working?

Are you working for your instructor? The instructor will make assignments and measure performance. Certainly he will be pleased to see progress and achievement in your work. However, his compensation is in no way affected by the effort expended by a particular student.

Are you working for your parents? Perhaps your parents have encouraged you to attend college and have made it possible financially. Certainly they will be proud of your achievements and will eagerly await each report on your progress. However, parents being as they are, they will probably be equally proud of you if you work 30 hr a week or 60, if you solve all the problems on that difficult assignment or only half, if you obtain an education or merely go through the motions.

For whom are you working? Whose career is being established? Whose financial future is at stake? Who will set the standards by which you will work? Who will determine whether your abilities will be developed to the fullest? Who? You. From now on you are your own boss, your own employee, your own critic. From now on you are working for yourself.

PURPOSES OF COLLEGE WORK

What are you attempting to accomplish? In general, one-third of an adult's life is spent earning a living, one-third in living, and the remainder resting up for the other two. It is now possible to earn enough in 40 hr per week to purchase all the necessities of life and a great many luxuries. A quick look at history indicates that the work week may soon be reduced to 35 or even 30 hr. There is time for a great deal of living.

One objective of college training is preparation for a vocation. In every person there is an instinctive urge to produce or construct or accomplish—to be a contributing member of society and be paid for it. In the case of the engineering student this future vocation is well defined and the engineering curriculum is designed to provide the necessary training.

A second major objective of college training is preparation for living, developing a personal philosophy, an appreciation of aesthetics, an understanding of one's relationship to others and to the universe. Opportunities for this type of training will be in the form of courses outside engineering and in extracurricular activities. It should be pointed out that for a professional engineer, living and earning a living cannot be separate. Engineering is a career, a way of life, and many of the engineer's pleasures and satisfactions will come from his work, which does not stop at 5 o'clock.

TYPES OF TRAINING AVAILABLE

In line with its objectives, a college offers a variety of different types of training. Among those available to engineering students are the following:

1. *Technical information:* Facts about the properties of materials and the characteristics of processes and circuits, physical principles governing the performance of machines and the behavior of systems
2. *Technical skills:* Ability to set up and solve problems, techniques of experimentation, manipulation of complex equipment and instruments, mathematical and graphical expression
3. *Other useful skills:* Ability in public speaking and report writing, writing contracts and specifications, setting up accounting procedures, handling conferences and interviews, conducting meetings
4. *Arts:* Creative writing, design and composition, photography, ceramic art, music, dramatic art, and industrial arts
5. *Attitudes:* Scientific attitude, intellectual honesty, tolerance, fair play, integrity, responsibility, respect for knowledge
6. *Knowledge of human relations:* Getting along with others, choosing companions, social amenities, teamwork, leadership, loyalty

7. *Cultural relations:* Human relations in the broader sense, the development of civilization, political science, civic responsibility, language and semantics, art and culture, economics

Each college course is set up to accomplish one or more of these types of training. Student activities provide additional training. The over-all college program provides an opportunity for the earnest student to become a contributing member of society. In working toward that goal, the student will learn from instructors, books, laboratories, and other students.

LEARNING FROM INSTRUCTORS

A college is literally a collection of scholars, organized for instruction and study. In addition to sharing in a common body of knowledge, each instructor "professes" knowledge in a special field. The professor makes available to the student his own knowledge and thus shares his own training and experience. The attitudes, methods, and techniques of the instructor are frequently more important than the factual information offered. The philosophy of an inspiring teacher will be remembered long after the subject matter has been forgotten.

Characteristics of Instructors

There is just as much variation in teachers as there is in students. No teacher is perfect in all respects; rather, each teacher offers a particular combination of qualifications. One instructor will possess a highly specialized zeal, while another will emphasize a broad general viewpoint. One will deal in abstract concepts, while another will present a practical viewpoint based on personal experience. Some teachers, especially in engineering, will stress the technical aspects of problems, while others will introduce the human and economic aspects. One instructor may be very careful in his work, fastidious in details, emphasizing logical organization; an equally successful teacher may employ unconventional approaches, jumping directly into the meat of the problem. Even as the young artist studies under a series of masters in order to develop skill in color, design, landscapes, or portraits, so the college student must endeavor to gain from each instructor what he has to offer.

Judging the Instructor

In general, a student is not qualified to judge the performance of a teacher. In the first place the student has no adequate basis for judgment since he knows neither the subject matter nor the most effective method of presentation. Second, there is no universally accepted definition of good teaching. In spite of these lacks, students do not hesitate to judge quickly.

Sometimes their reasoning goes like this: "*I* took the course; *I* learned nothing. Therefore, *he* is a poor teacher."

Responsibility of the Student

The responsibility for learning is on the student. In addition he has the responsibility for picking and choosing among the ideas and concepts which are presented to him. He must learn early not to accept everything which is offered. The ability to consider critically, to weigh and evaluate in terms of the evidence available, to accept or reject only after critical consideration, is one of the marks of an educated man.

In each course, the student should follow the teacher's instructions even though they do not always agree with the student's ideas. The young engineer's bosses on the job will not always agree with him either. Ability to follow instructions is a desirable characteristic which some students have to learn. In following the suggestions of different teachers, the student learns a variety of methods from which he later can choose the best in a given situation. Of each instructor the student should say: Here is a man with certain training, experience, and personal characteristics. He is my partner in a learning process. How can I make the greatest use of this opportunity?

LEARNING FROM BOOKS

In the classroom the student can take advantage of the experience of the instructor, but in books the student has available the observations and thoughts of many men from all parts of the world from all of recorded time. Truly, the printed word has made possible the progress of our civilization.

Learning by Reading

The purpose of an author is to record ideas in the form of words and other symbols. The reader must convert those symbols back into ideas and store them ready for use. There is a great difference between passive reading and active studying. All too frequently the reader runs his eyes over each word, mechanically "translating" the symbols, only to find when he reaches the bottom of the page that he has no idea of what he has read. One efficient procedure is to *read*, *recite*, and *apply*.

Read for understanding. Read in one continuous session a complete unit of the subject. In technical material this may be one short meaty paragraph; in descriptive material it may be a page or two. Be sure of the meaning of every word, using the dictionary where necessary.

Recite to yourself the substance of the paragraph using your own words.

Convert mathematical symbols into words and equations into sentences. As an aid, ask yourself what the author is trying to express. If the meaning is not clear, phrase a specific question covering the difficulty. Frequently stating the question is a big step toward the answer. If you cannot clear up the difficulty, take the specific question to the instructor.

Apply the essential idea to a practical situation. The material studied becomes useful only when it can be applied. If it is factual material, visualize how it could be used. If it is a quantitative principle, employ it in solution of a problem. If it is an abstract concept, apply it in a realistic setting. Until the material can be applied, it has not been mastered.

Aids in Reading

In some respects reading is a skill which can be improved by purposeful practice. Experiments show that for most people reading speed can be greatly increased without sacrificing understanding. Because of the importance of reading ability in college training and in professional practice, time spent in improving reading efficiency and speed is well worth while. It has been suggested that an engineering student should develop two reading rates, high speed for nontechnical or descriptive material and slower speed for concentrated technical material.

Usually reading will be more effective if some physical activity is coupled with the mental effort. *Underlining* key phrases will force you to analyze paragraphs and focus attention on the essentials. *Notes* in the margin or in a notebook will accomplish the same thing and in addition permit you to add your own comments. *Outlining* consists of analyzing the material into major and minor subdivisions and listing the essential points under each.

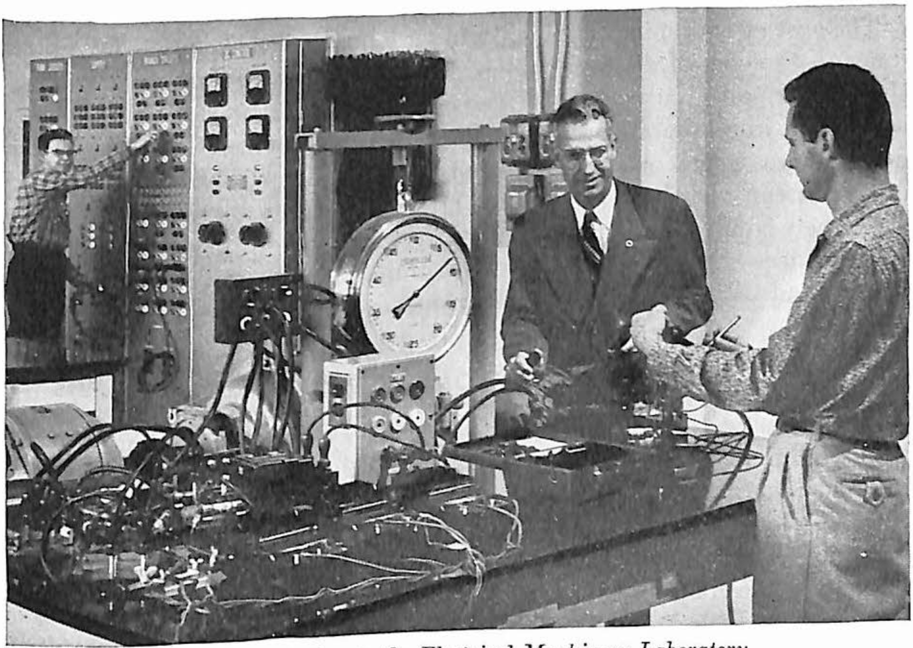
Outlining is valuable for three reasons: in the first place, it concentrates on a page or so the essential material of a large section and therefore facilitates your grasp of the whole. Second, it requires that you analyze the subject matter and determine not only the important points but also the relationships among them. In the third place, a good outline provides an excellent basis for review. For a speaker or an author, a "topic" outline with just the key words will serve to recall the ideas; in outlining study material, however, longer phrases or complete sentences will be necessary.

LEARNING IN LABORATORIES

Books are limited to the type of information which can be presented on the printed page, and the instructor's experience and observations come to the student secondhand. In college laboratories firsthand experiences with actual equipment are available.

Purposes of Laboratory Training

Laboratories provide training which cannot be gained otherwise. It is one thing to read in a book that a decrease in field current in a shunt motor produces an increase in speed and to understand the equation which indicates that if the field current goes to zero, the speed increases without limit. It is something entirely different to be in a junior laboratory when a beginning student opens the field circuit by mistake and the ominous whine of the overspeeding machine, drowning out the usual laboratory noise, rises to a fearsome pitch before the instructor can grab the circuit breaker.



Experimentation in the Electrical Machinery Laboratory

Experimentation forms the basis for the development of all science; progress in engineering and science is made by formulation of theory, checking the theory in the laboratory, and publishing the results. In the school laboratory the student has an opportunity to work with flexible power supplies, versatile machines, and precise instruments. Laboratory courses provide training in designing experiments, providing the necessary controls and instrumentation, making and recording observations, and reporting the conclusions reached. (*San Jose State College Photo.*)

The purpose of laboratory work is not just to illustrate the theory of the text and lecture. Rather it should serve to emphasize the distinction between theory and practice. It should develop skill in the experimental method which forms the basis for the development of all science. It should provide practice in observing, recording, and reducing data and drawing conclusions therefrom. It should lead to an appreciation of the limits of precision of scientific measurement. It should, in the case of engineering, provide an understanding of the practical problems of starting, controlling, and operating engineering equipment.

Laboratory Work

The cost of equipping and maintaining laboratories is one of the major items in the cost of offering engineering training. You should make sure that you take full advantage of these unique opportunities. Usually the time spent in a laboratory is limited, and prior preparation for the day's work is necessary. You should carefully study the experiment instructions until you can visualize the conduct of the experiment. If it requires the use of new equipment, a preliminary trip to the laboratory or the library may be necessary. You may wish to prepare forms for recording data rapidly and list the necessary instruments.

LEARNING FROM STUDENTS

In discussing the work of engineers, it was pointed out that skill in human relations is important in all functions. Just as laboratories provide an opportunity to work with actual equipment in real situations, so college life constitutes a human laboratory wherein you can work with, learn from, and learn about people. In terms of mental characteristics and objectives, the college population is highly selected. However, in terms of social, economic, religious, and racial backgrounds, most schools enroll a broad cross section of students with a correspondingly broad opportunity to learn from them.

Teamwork

One characteristic of work in a complex field such as engineering is the necessity for teamwork. College training, however, emphasizes individual effort; indeed, cooperation under certain circumstances is strictly prohibited. In an engineering curriculum teamwork is encouraged in laboratory and project work.

Laboratory Work. Work in the laboratory usually requires the cooperative effort of several students in operating equipment, making simultaneous measurements, and recording data. Ordinarily the position of leader is rotated among the members of the party; the well-prepared leader can save a great deal of time by being sure in advance of the procedures to be followed and the form and range of the required data. Laboratory work is similar to real situations in that each group is only as efficient as its weakest member and usually work cannot proceed until all members are in agreement. This has led to the seemingly paradoxical rule for the time required for laboratory work: "Three men, three hours; four men, four hours."

Projects. Most engineering courses are specialized in that they emphasize training in only a single aspect of engineering and the problems solved are of limited scope. For example, in the usual course in thermodynamics, gasoline engines are discussed in terms of the heat power aspects with no attention to the problems of material selection, corrosion, electrical ignition, or economics of production. It is now common to offer advanced courses in which the training from several basic fields is utilized in solving complex problems or projects. These large projects require the cooperation of several students and are carried out under conditions similar to those in an actual engineering office.

Student Societies

Of importance to the engineering student are the engineering societies and student chapters of technical societies. They provide opportunities for working with other students, developing leadership, making contacts with professional engineers, taking field trips to local industries and projects, and carrying on social and recreational activities. Serving on project committees helps to develop two characteristics which are of great interest to employers—the ability to work with others and the ability to get things done. The student engineering societies are especially important because the usual engineering student does not have time enough for all-college activities.

College Activities

For the student who can afford the time, student activities provide learning opportunities of considerable value. Participation in student government develops the ability to work with and for fellow students. Debating, drama, and music activities are valuable as recreation during college days and later in professional life. Participation in athletics develops physical strength, skill and stamina, and also teamwork. Of particular value are those sports which can be continued after college.

Living Groups

One reason college training is so important is that it usually covers a period of life in which rapid mental and psychological changes are taking place. This is a time for "growing up," and for the typical student, it is the first time in which he is on his own, making his own decisions. Compared with the closely controlled high school situation, college offers a great deal of freedom. The college student is free to select his program of study, to decide how he will invest his time and money, to select his friends and choose his leisure-time activities. The rooming house, dormitory, or fraternity is his college "home," and its members become his "family," exerting many of the influences expected in a family. Here is another valuable opportunity to work with people and to learn from them.

THINKING

The over-all purpose of all college education is to train its students to think. Just what is thinking? In general, thinking consists of formulating questions and answering them. Thinking requires two things: a store of ideas, principles, and facts and the ability to put them together to meet a new situation or solve a new problem.

The art of thinking is called logic. It is not possible, however, to learn to think by studying logic. Similarly it is not possible to develop muscles by reading books on weight lifting. To develop "mental muscles," they must be exercised in vigorous mental activity. The mind can never be trained to solve difficult problems by working on easy problems. Reasoning by analogy with physical training, it would appear that during the training period, in college, the mind must be disciplined by mental effort beyond what will ever be required in the future.

Many engineering jobs require the ability to think creatively—to visualize an entirely new idea or plan or device. Engineering schools are eager to provide training in creative thinking, but at the present time no one is sure how this can be done. Ideas seem to come almost unbidden when the necessary mental sifting and sorting has been done. One approach to the generation of new ideas is the so-called "brainstorm" session. A group of people with the necessary background of training and experience are called into conference on a given problem. They are asked to propose solutions to the problem without considering the practicality of the solutions. In this way is overcome the reluctance of the usually conservative engineer to propose a plan without careful consideration. Each proposal suggests other possibilities, and relieved of the necessity of justification, the brainstormers can let their fancies take flight. A somewhat similar process takes place when, some time after a period of concentrated thought, the less restrained subconscious mind comes up with a useful idea.

STUDYING

For each hour spent in a lecture-type class, the efficient student is expected to spend approximately 2 hr outside in study and preparation of assignments. The inefficient student will have to spend more time and may wish to budget his time.

Time Budget

A financial budget is not for the purpose of saving money but rather for ensuring that money will be available to spend for desired items. Similarly, a time budget will help to make sure that time is available for recreation, social activities, and sleep as well as for the necessary studying. A time budget can be made out on a weekly basis, showing scheduled class hours, designating definite periods for outside work in specified courses, and including adequate time for relaxation. One great advantage of following a schedule is that it encourages efficiency. It is poor policy to try to mix social activities and study sessions. On the other hand, there is no benefit from recreation time spent in worrying about unfinished assignments.

The time schedule should be tailored to suit the individual. Some physiologists believe that persons vary in regard to their cycles of greatest mental activity. Some, the "A.M." type, jump from bed wide awake and ready to work; usually they get sleepy relatively early and should not plan on late studying. The "P.M." type, on the other hand, awakens slowly, takes a long time to get under way, but will still be going strong at midnight. Perhaps the "P.M." type should avoid early classes, if possible.

Efficient Study

Studying requires a great deal of intensive effort. In order to conserve time, the effort should be concentrated and free from distractions. Efficient study can be made a habit which will be useful throughout a professional career. The fact that the student is working for himself provides an incentive for improvement in his work habits. As mentioned previously, reading is not study, and going through the motions will never produce results. Efficiency will be increased if the student periodically asks himself: Why am I doing this? What am I trying to accomplish? What is the best method?

Physical Considerations

The only essential requirement for productive study is an eager, receptive mind; the properly motivated student can work under almost any conditions. However, because efficient study requires an all-out effort, all distractions, annoyances, or discomforts should be minimized and a perfect physical situation provided. The room should be quiet, at a comfortable temperature, and well ventilated. The chair and table should be selected to provide optimum conditions for work rather than rest; a straight chair and a table height suited to the individual should be used. Since much studying involves vision, lighting is important; the light should be bright enough for easy vision and located so as to avoid glare or shadows. Tools such as pen, pencil, paper, slide rule, and drawing instruments should be of good quality so that the student is not handicapped in his attempt to do good work.

STUDENT WORK

In the typical lecture-recitation course, the instructor sets up a group of objectives in a given subject field and outlines a course to accomplish these objectives. He organizes a series of lectures, selects a textbook which the student can study on his own, makes assignments to guide the work of the student, conducts class discussion of important points, gives oral and written examinations to check on the student's progress toward the course objectives, and evaluates the student's work in terms of grades.

Lectures

The lectures provide the instructor with an opportunity to present material which is especially tailored to meet the needs of the class. The student should take notes which can be studied after class and reviewed at examination time. In order to be useful, the notes must be coherent and complete. A page of disorganized items, figures, and formulas will soon be "cold" and useless. Sometimes it is justifiable to spend time in rewriting notes because in doing so the material is studied while it is being put into useful form. A good set of notes will indicate the points stressed by the instructor and include illustrative examples for review. Questions can be noted during the lecture or the review and taken to the instructor for clarification.

Assignments

Every assignment handed in is a report to the instructor on the student's progress. In addition to the ideas presented, the student should strive for an effective form of presentation. Engineering work is expected to be neat, well organized, and in good grammatical form. Sketches indicating physical relationships in problems are helpful. In many assignments the ability to follow instructions is important. Because the engineering assignments are similar to future work, the student should set high standards of performance for himself.

Examinations

An important feature of college training is the series of examinations covering each phase of the course work. Some students are more skilled than others in the art of taking examinations. The less skilled student must compensate by being better prepared. Actually, the taking of an examination starts in the study room; no amount of skill can make up for lack of preparation.

Assuming you are well prepared, you can do a better job by following certain rules, always bearing in mind the purpose behind the examination. Read all instructions carefully, and follow them as closely as possible. If the examination is short enough, read all the questions and note those for which you are well prepared. Answer these *first* in order to get credit for what you know and to build up a measure of confidence. Do not spend too much time on any one question; in some examinations you are not expected to be able to answer all questions completely. Write clearly, and do not crowd your work; a solution which cannot be followed by the instructor usually receives little credit even if correct.

Grades

Sometimes there is a difference between the student's evaluation of his work in a course and the grade assigned by the instructor. Just what do grades measure, and why are they important? They are important because they become part of your permanent record of academic accomplishment. They are of interest to employers because they are accepted as measures of ability in engineering course work. It is recognized that there is a big difference between college work and work on the job, but grades constitute a positive record of ability in one aspect of engineering. The pattern of grades is more important than the over-all average. A student with low grades in advanced mathematics and science will have difficulty in obtaining a position in research. A student with D and F grades, even if balanced by A's and B's, gives the impression of spotty performance.

A PARABLE

A certain group of young men purchased a 4-year meal ticket for $10,000. Each day there was spread before them a feast: body-building proteins, energy-supplying carbohydrates, necessary vitamins, intoxicating beverages, and pleasant desserts.

Some ate between meals and were never hungry enough to benefit from what was available. They had interests off campus and did not take advantage of regular attendance.

Some ate only the heavy proteins and neglected the vitamins and the satisfying desserts. They were the "grinds" interested only in class attendance and homework assignments.

Some filled up on sweets and had no appetite for the important growth foods. These were the playboys who concentrated on social affairs, fraternity activities, football games, and romance under the library arch.

Some became intoxicated and had no appetite for food. They were the "activities hounds" who, in quest of fame and campus prestige, served on committees, ran for office after office, or burned themselves out on the athletic field.

Some selected for themselves a balanced diet: some hard study of basic courses for growth, a portion of interesting major courses providing motivation, the necessary vitamins of class and organization activities, and for dessert a moderate helping of recreation and romance.

A college program offers an abundance of opportunities for learning; the wise student selects carefully and uses his time efficiently.

11

PREVIEW OF AN ENGINEERING CURRICULUM

Engineering was defined as "the professional art of applying science to the efficient conversion of natural resources to the benefit of man." The professional engineer must study the sciences and their application, material and power resources and their conversion, and man himself. As a group of engineering leaders* recently agreed, "The ultimate goal of engineering education is the development of able and responsible men fully competent to practice on a professional plane . . . who will eventually lead the profession to new heights of accomplishment through creative practice. . . . " The practice of engineering is a lifetime career which includes learning on a continuous basis. The first stage of education is college training, which provides education for citizenship, for intelligent living, and for earning a livelihood.

EDUCATION FOR CITIZENSHIP

Man is a social animal, and all his desires and actions are the results of his relations with other members of his social groups—his family, his company, his church, his club, his government. Every normal person has an urge to be a contributing member of society and to be recognized by society for that contribution. This same urge is found in even the hardened criminal, although it may be badly distorted.

The college is a social institution which has as one of its primary responsibilities the preparation of young people for citizenship. In carrying out this responsibility, the college provides an atmosphere which tends to develop desirable attitudes and in addition offers specific courses of training in English, the social sciences, psychology, physical and biological sciences, and mathematics.

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* Committee on Evaluation of Engineering Education, American Society for Engineering Education.

English

Relations among individuals and within a social group are dependent upon communication of ideas. Of vital importance is facility with the written and spoken words of the Americanized version of the English language. Some new forms of communication such as comic books and television place less emphasis on the written word, and it may be that skill in reading and writing will become less important to the general public. For professional men and for leaders in all fields, however, skill in all forms of English usage is of the greatest importance. Some engineers fail to realize this while in college and, finding themselves handicapped in professional practice, must attend evening classes or enroll in correspondence courses.

In the words of Lord Bacon: "Reading maketh a full man; conference a ready man; and writing an exact man." In our daily lives we come in contact with a few outstanding men. Radio and television provide brief opportunities to hear from great individuals. In books, however, we have access to the thoughts of the best minds of all time. Certainly reading makes a "full" man.

Writing can be done at a leisurely pace, in a quiet place free from distractions. Speaking requires thinking on your feet under pressure—being a "ready" man. Oral reporting can be made easier by planning and outlining just as for a written report. Much of the nervous tension which plagues most inexperienced persons when speaking in public is due to a fear of being poorly prepared. Proper planning and preparation will remove most of the tension, and practice and experience will take care of the rest, leaving the speaker in a condition to do the best job possible. Courses in public speaking provide voice development, training in speech organization, and the necessary practice in delivery.

No two words mean exactly the same thing. The effective writer is skilled in selecting just the right word to express his idea. Some years ago an exhaustive study was made by Stevens Institute of 200 major business executives. It was found that the most universal characteristic of these outstanding leaders was an extensive, accurate knowledge of the exact meanings of words. As you read, build your vocabulary; never let an unknown word slip by without consulting the dictionary. As you write, exercise your vocabulary by always striving for the proper word. In all your compositions follow the rules of good grammatical construction in order to convey to the reader your precise meaning. Keep your standards high; you will never exceed them.

Social Sciences

To be a good citizen requires a knowledge of history, an understanding of government, an appreciation of economics, and a knowledge of sociology.

History. The history of civilization has followed closely the history of engineering. Major engineering advances in transportation, communication, and power generation have affected cultures, governments, wars, and various sociological developments. A study of history is important because a knowledge of the past is helpful in predicting the future. In some areas history indicates continuing trends, and in others cyclic variations are to be expected. History provides a frame of reference from which current and future happenings can be viewed with the proper perspective.

Government. A glance at any newspaper reveals the extent to which government influences our daily lives. Political science is concerned with the problems of organization and administration of governmental units which have been established to carry out, in an orderly way, the will of the people. Federal, state, and municipal governments perform for the corresponding social groups those functions which cannot be carried out on an individual or volunteer basis. The representative form of government which has been developed in the United States provides greater individual freedom than any other comparable political organization. The combination of abundant resources, universal education, and freedom of individual action has brought the United States to its present position of world leadership. An understanding of how our government was established, how it has developed, and how it operates is required for effective citizenship.

Economics. The science and theory of the production, management, and distribution of wealth is called economics. Economics is concerned with the business principles involved in development, manufacture, and marketing of goods; public and private finance; costs, prices, and profits; investments, rents, interests, and wages; and governmental regulation and taxation. All major engineering and business problems and most public projects involve financial aspects which require for their consideration a strong background in economic theory and practice.

Sociology. Sociology is the science of society and is concerned directly with discovering the fundamental laws which apply in social groups. Sociologists analyze and classify social facts, study the history of social development, determine the common characteristics of different societies, and attempt to discover the general laws which govern social evolution. Sociologists make comparative studies, use statistical methods, and employ the principles of psychology in the search for understanding. An introductory sociology course is usually a study of their findings.

Psychology

Whereas history is the broad story of man's development and sociology is concerned with the behavior of groups, psychology is directed toward the study of the individual mind. Since all mental processes are accompanied by nerve action, there is a close correlation between psychology and physiology. Another close relative is the field of psychiatry, which is concerned with the treatment of mental diseases. Applied psychology includes business and industrial psychology, which have become so important that they have attained independent status. Applied psychology deals with the relations among emotions, mental activity, and physical action in workers, supervisors, salesmen, customers, teachers, students, associates, and strangers. In any relationship with people a knowledge of psychology is valuable.

Natural Science

In the last 100 years man has made considerable progress in social science. In comparison, however, his progress in natural science has been tremendous. The key to the rapid progress in physical and biological science has been the use of the experimental method. The subjects have been inanimate objects such as chemicals, forces, electric charges, and light waves or unresisting plants, bacteria, dead animals, and lower forms of living animals. With man in complete control, these pliable subjects are studied under laboratory conditions where the number of variables is carefully regulated. In contrast, the student of social behavior has to work with a very difficult subject—man himself. His data consist of historical studies or statistics on complex social occurrences where the number of variables is great. As a result this has become known as the Age of Science, and the natural scientist and the scientific method are held in high public esteem. At one extreme, science has contributed to international tension through atomic-bomb developments; at the other, science has, in 70 years, increased the life expectancy of the average man from 38 to 70 years through advances in medical treatment, improved sanitation, and better nutrition. Certainly no one can be a participating member of society without an appreciation of science and its methods.

Mathematics

It has been remarked that no matter how much a thing has been studied, until it can be measured very little is actually known. In other words, it is only when a relationship has been expressed in quantitative terms that progress toward understanding has been made. Mathematics is inseparable from science and should be a part of every education.

EDUCATION FOR INTELLIGENT LIVING

Education for citizenship emphasizes the relationships among men in social groups. The complete education must also consider the inner man—his soul, his emotions, his response to beauty, his relationship to the universe. College provides an ideal atmosphere for developing an interest in philosophy, aesthetics, fine arts, and practical arts.

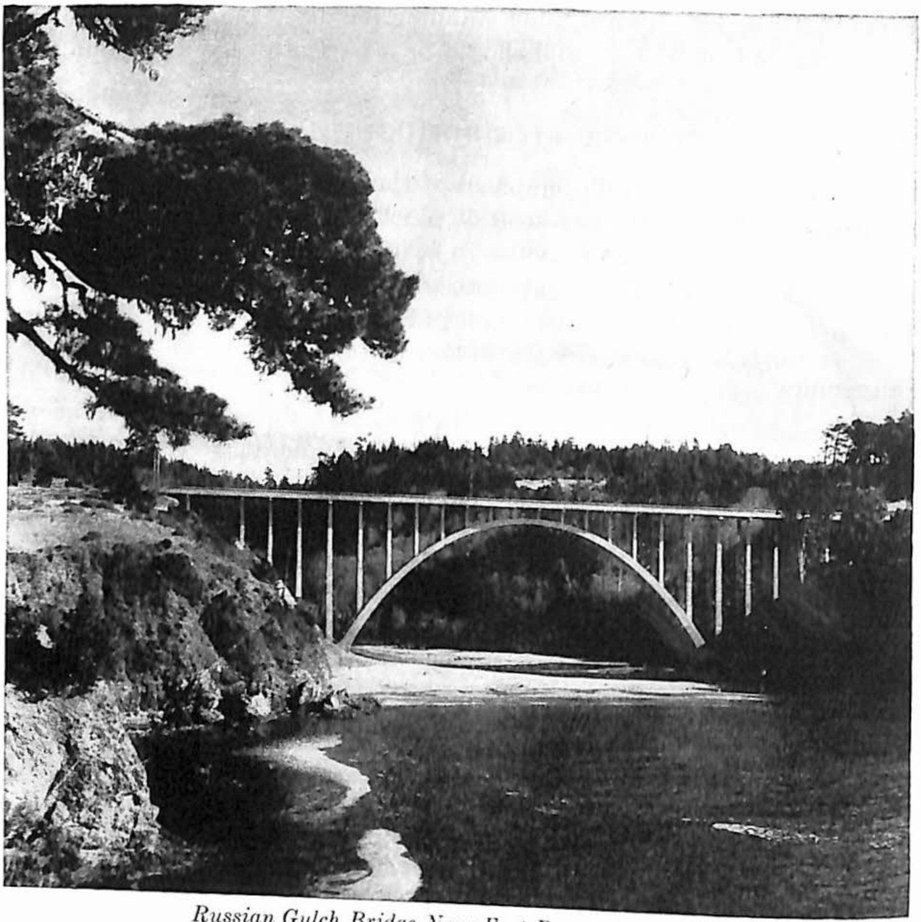
Philosophy

By definition, philosophy is the love of and the search for wisdom. Originally it included all knowledge—mental, moral, and natural. Out of philosophy have developed physics (philosophy of material and physical facts), theology (philosophy of God and the divine order), and psychology (philosophy of the mind). Ethics is the branch of philosophy that deals with questions of right and wrong. A code of ethics is an integral part of every profession, but an individual must establish his own personal set of standards. No person is intellectually mature until he has established his own personal "philosophy of life" which defines the values to be respected, the goals to be sought, and the rules to be followed.

Aesthetics

Aesthetics has to do with the beautiful in life as distinguished from the useful and the moral. A thing has beauty when it delights the eye, the ear, the intellect, or the aesthetic sense. Enjoyment of life is heightened when one's eyes are opened to the beauties around him. The first step in developing an aesthetic sense is to study the works of art which are a part of our culture. While the ability to create beauty is granted to only a few, all of us can broaden our lives by developing good taste and a critical appreciation of the beauties around us.

A common criticism of engineers and scientists is that they lack aesthetic sense. It is true that the engineering program permits little time for formal study of fine arts. However, Socrates taught that beauty and utility are one; in other words, a true functional design necessarily possesses beauty. This is the basis of the beauty to be found in nature—the alluring blossom, the outreaching tree, the poised leopard, the soaring hawk. In each of these beauty is an outgrowth of specialized function. In the same way the suspension bridge and the racing car possess functional beauty. In contrast the automobile has passed through the period of functional design, and now the emphasis is on style and ornamentation. This shift in emphasis has increased sales, and the resulting mass production



Russian Gulch Bridge Near Fort Bragg, California

The engineer is not always permitted to display his creations in such a delightful setting, but here he has made the most of the opportunity. This light and graceful reinforced-concrete bridge is an illustration of how purely functional design can be aesthetically satisfying. Up from the rocks springs a concrete arch which supports, by means of finely scaled spandrel columns, the highway in the sky. (*California Division of Highways.*)

has reduced costs. As a result the car buyer gets much more for his money, but he may not receive full aesthetic satisfaction.

The Fine Arts

The fine arts include those which result in the creation of beauty. The artist interprets and records the beauties which he perceives. Paintings make their appeal to the eye through line and color. Sculture permits work in three dimensions. Architecture makes use of space, line, color, light, and texture in providing a beautiful setting. Music interprets natural beauty or emotion through complex combinations of tone, melody, and rhythm. Literature, working through the intellect by means of word pictures, arouses emotions and provides aesthetic experiences. Drama combines spoken words with living pictures to achieve its effect. An appreciation of aesthetics in its various forms is characteristic of the highest state of mental development.

The Practical Arts

Creation or construction provides great personal satisfaction, but in this age of specialization, many jobs are devoid of any creative opportunity. In the past skilled craftsmen converted raw materials into finished products. Now these products are fabricated by automatic machines, and frequently human beings perform only repetitive tasks. Also, in our complex society many jobs are far removed from the constructive operations. As a result most persons have little opportunity to obtain creative satisfaction from their daily work.

Most colleges offer some training in the practical arts. Drafting, cabinet work, metalwork, cooking, dressmaking, and weaving provide opportunities to develop productive skills. For the professional man or woman these become ideal leisure-time activities. Nothing can replace the satisfaction gained in being able to say: "I made that."

EDUCATION FOR ENGINEERING

Education becomes more meaningful when it serves as a step toward a career. In the case of engineering this ultimate goal is quite clear and well defined. The integrated engineering program is the result of nearly 100 years of growth and development, and as would be expected, the courses of training which combine to make up the curriculum for a given type of engineering training do not vary greatly from school to school.

The Engineering Curriculum

The typical engineering curriculum includes training in mathematical, graphical, and verbal expression; the basic sciences of physics and chemistry; certain auxilliary sciences; and the fundamental engineering sciences (see Table 16). Usually this basic preparation is the same for all students at a given engineering school. Specialization to meet the needs of various groups of students is provided by *majors* or *options*—combinations of courses relating to a particular function-branch category.

Schools which emphasize training for the design function offer majors in civil, chemical, electrical, mechanical, metallurgical, or other branches of engineering. Students selecting electronic engineering, for example, might take courses in vacuum-tube theory, communications engineering,

Table 16. Components of the Engineering Curriculum

Basic sciences		Means of expression
Physics:	Mathematics:	Verbal:
Mechanics	Algebra	Composition
Heat	Trigonometry	Public speaking
Light	Analytic geometry	Report writing
Sound	Calculus	Graphical:
Electricity	Advanced calculus	Technical drawing
Magnetism	Differential equations	Descriptive geometry
Solid state		Graphs and charts
Nuclear		
Chemistry:	Other sciences:	Mathematical:
General	Biology	Numbers
Organic	Geology	Symbols
Analytical	Economics	Operations
Physical	Psychology	
	Engineering sciences	
Materials and processes:	Engineering mechanics:	Mechanics of solids:
Metallurgy	Statics	Tension
Properties	Kinetics	Compression
Processes	Kinematics	Torsion
		Bending
Mechanics of fluids:	Thermodynamics:	Electrodynamics:
Properties	Processes	Circuits
Fluid statics	Cycles	Fields
Fluid flow	Engines	Machines
Hydrodynamics	Heat transfer	Electronics
	Engineering technology (Illustrative examples)	
Surveying	Ceramics	Air conditioning
Hydraulics	Refrigeration	Electrochemistry
Electronics	Communications	Municipal engineering
Industrial electronics	Plant layout	Sanitary engineering
Elasticity	Instrumentation	Highway engineering
Illumination	Oil production	Chemical technology
Pyrometry	Ore preparation	Internal combustion
Aerodynamics	Production processes	Time and motion study
Structures	Unit operations	Construction methods
Mining	Machine design	Electrical machinery
	Mine operations	

industrial electronics, servomechanism, etc. Majors are also available in the production function of mechanical engineering or the construction function of civil engineering. Combinations of engineering and physics provide preparation for research, and engineering and business training can be integrated in a management curriculum. Majors in application and sales cut across several fields.

The Engineering Schedule

Engineering curricula are highly integrated; courses follow each other in a definite sequence with advanced courses utilizing the training of earlier courses. Study the curricula listed in your college catalogue, and note the introductory nature of first-year courses and the prerequisites listed for advanced courses. In many schools offering 4-year curricula, the first year includes elementary engineering, mathematics, chemistry, and English or other nontechnical studies. Physics is frequently delayed until the student has a strong background in mathematics, perhaps some calculus to use in motion problems. The study of metallurgy requires a knowledge of chemistry and therefore may be scheduled in the second year.

A knowledge of physics, chemistry, and mathematics serves as a foundation for studying the engineering sciences in the third year. The fourth year may be devoted to engineering technology, the application of the engineering sciences to processes, structures, machines, circuits, and systems. Here, the emphasis is on dealing with new situations in terms of fundamental principles rather than learning how things have been done in the past or how they are being done at present.

The Basic Sciences

College chemistry and physics are extensions of high school courses with more emphasis on quantitative relations requiring more advanced mathematics.

Chemistry deals with the composition and properties of substances and the transformations which alter their identity. General chemistry includes a study of the elements, their compounds, and the basic chemical laws which govern their chemical behavior. Organic chemistry is concerned with the compounds of carbon, which are more numerous than those of all the other elements combined. These compounds were originally called "organic" because it was thought, erroneously, that they could be produced only by living organisms. Analytical chemistry is concerned with the detection ("qualitative") and measurement ("quantitative") of substances.

Physics deals with the phenomena of the inanimate world. It treats the properties of matter and nonchemical changes. Classical physics includes mechanics, heat, light, sound, electricity, and magnetism. Modern physics is concerned with the structure of the atom and the nucleus and cathode rays, X rays, cosmic rays and radioactivity. Mathematics is discussed in detail in Chap. 14.

Engineering Sciences

The engineering sciences are extensions of the basic sciences emphasizing fields of particular importance in engineering. Training in the engineering sciences is provided by courses, or sequences of courses, which may be grouped into six categories: materials, mechanics, strength of materials, fluid mechanics, thermodynamics and electrical engineering. Recently a committee of the American Society for Engineering Education proposed a subdivision into six engineering sciences which differ only slightly from the more customary approach followed here.

Materials and Processes. Materials employed in engineering structures and devices are valuable because of their properties: strength, hardness, elasticity, ductility, malleability, conductivity, resistivity. Courses in materials define and discuss the properties of technically important materials, their metallurgy, production, and heat treatment. The emphasis is on understanding the fundamental nature of the structure of materials, although some training is given in the selection of materials for engineering use. Processes courses provide training in methods of manufacture such as machining, welding, forging, riveting, punching, casting, and die casting. The student learns the basic principles of operation and the capabilities and limitations of modern processes and machines.

Engineering Mechanics. These are courses in the fundamental principles of statics and dynamics and their application to idealized structural and mechanical problems. The student uses physics and mathematics to solve problems involving rigid bodies under the action of various types of forces. Problems include bodies in equilibrium, translation, and rotation. Both analytical and graphical methods are employed with emphasis on logical procedures. A typical problem in statics would be: Given a truss of specified dimensions and loading; find the forces in the members of the truss.

Mechanics of Solids. This course is sometimes called "strength of materials" because it involves the application of the principles of mechanics to actual structural elements composed of practical materials of limited strength. Included are problems in tension and compression as in the elements of a bridge, torsion as in a shaft, and bending as in a beam. A typical problem would be: Given a cantilever beam to support a specified load; find the dimensions of the appropriate steel I beam to support the load safely and calculate the deflection under the load.

Mechanics of Fluids. This is an elementary course in the properties of fluids and the principles which govern flow in open and closed conduits, around submerged objects, and through measuring devices. It provides a basis for subsequent courses in hydraulics and aerodynamics. The student learns to apply fundamental principles in selecting pipe sizes and calculating the power required for given flow conditions. A typical problem would be: Given a certain oil which is to be pumped at a given rate through a pipe of specified dimensions; determine the type of flow, the pumping head loss, and the horsepower required.

Thermodynamics. Thermodynamics means "heat power" and relates to the principles governing the interchange of heat energy in accordance with the law of conservation of energy. Nonflow and steady-flow processes of gases and vapors are analyzed, and the relations among temperature, pressure, velocity, heat, and work are developed. These relations are then applied to the cycles of operation of internal-combustion, air-compression, steam-power, and refrigeration equipment. A typical problem would be: Given an idealized automobile engine with a certain compression ratio operating under specified conditions; find the horsepower output and efficiency.

Electrodynamics. In this course the basic electrical quantities are defined in engineering terms and the energy relations in resistive, inductive, and capacitive circuit elements are developed. Electric and magnetic fields are discussed, and equivalent circuit elements are derived. The fundamental principles are applied to the solution of problems involving direct-current, alternating-current, resonant, and coupled circuits. Elementary motors, generators, transformers, rectifiers, oscillators, and amplifiers are analyzed. A typical problem would be: Given the characteristics of an electrical generator; find the output voltage variation from no-load to full-load operation, and calculate the full-load efficiency.

Engineering Applications

Knowledge of the basic sciences and the engineering sciences is not an end in itself for the engineer; as a "doer" he must be able to apply that knowledge creatively. In one broad sense, all engineering training is directed toward "design"—analysis of a problem and synthesis of a solution. Creative design, whether it is design of a device or a procedure or an organization, requires a knowledge of the art of engineering and its present limitations and a knowledge of the science which permits removing those limitations.

To illustrate the type of training provided in advanced work, consider three specific courses.

Microwave Theory. A microwave antenna is to be developed for a new type of navigation aid. The necessary background material includes a knowledge of antenna fundamentals, radiation patterns, and analysis of antenna arrays as well as an understanding of microwave principles, network theory, and methods of analysis of wave guides and cavity resonators. Generalized mathematical approaches are used.

Machine Design. A small bench-type drill press is to be manufactured; the student is asked to submit an engineering design of a portion of the press. In preparing the design, the student uses his knowledge of mechanics in determining the forces in the various members, strength of materials to calculate the stress distribution, properties of materials to select the desirable materials, production processes to determine how parts should be fabricated, drafting to present the design in final form, and economics to determine the cost and desired selling price.

Construction Methods. A small store building is to be constructed, and an engineering firm (represented by three students) has been asked to submit a bid. The student engineers "take off" from the drawings the quantities of concrete, reinforcing steel, roofing, etc. They "design" the method and procedure of construction, estimating the time required for the various craftsmen. They design the formwork and any other temporary structures. They select the most desirable power equipment. All decisions are made on the basis of economy consistent with the quality indicated in the specifications.

SUMMARY

Engineering is a lifetime career in which college training is but the first step. A complete education prepares the graduate to take his proper place in society, provides him with the background to enjoy life to the fullest, and enables him to earn a living in a satisfying occupation. Of itself, the engineering curriculum is a broad program of training which goes a long way toward meeting the over-all objectives. One of the virtues of engineering training is that it represents an effective integration of courses from many fields with each course contributing to the over-all development of the student.

ASSIGNMENTS

11-1. Study the engineering curricula outlined in the catalogue of the college of your choice. Analyze the curriculum you are planning to follow, and determine what percentage of the total units or credit hours is devoted to each of the following: basic science, engineering science, technology, nonengineering, elective subjects, other.

11-2. Analyze the curriculum you are planning to follow, and list the names of the courses which appear to be designed to provide education for citizenship and education for intelligent living.

11-3. Study the curriculum you are planning to follow, and select three senior-level courses which appear interesting. List the names of the courses which must be taken as prerequisites for the advanced courses, including courses preparatory for the prerequisites themselves.

12

ORAL AND WRITTEN REPORTS*

For many years you have been working at developing your ability in self-expression. After that first "Ma-ma" which meant so much to your mother, you quickly learned to express your ideas and wishes orally. In your first years at school you learned to associate ideas with abstract symbols—words. Then, wonder of wonders, you learned to write your own mystic symbols which others could translate. Later on you began to analyze sentences; you learned the parts of speech—the nouns, verbs, adjectives, and adverbs—and the function of each. Understanding the functions of the component parts, you were able to do a better job of synthesis—putting the parts together. Your subsequent training in English probably emphasized the clear expression of ideas with continued practice to help you eliminate mistakes in the mechanics of writing, spelling, punctuation, grammatical construction, and word usage.

In spite of all the training students have had before entering college and the instruction and practice received in college, a common complaint of employers is that their new employees cannot write satisfactorily, cannot compose simple business letters, for example, without glaring errors. Perhaps one reason is that students have not been properly motivated; they have not been made to realize the importance of skill in expression in their own careers.

The purpose of this chapter is twofold. First, it will call to your attention very early in your college training the importance of verbal expression in engineering and indicate some applications to your future progress. Second, some preliminary training will be given in the form of expression which is so common in engineering, the writing of reports. The emphasis in this discussion will be on the type of planning called *design*, which is found in all engineering work.

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* Much of this chapter is based on "Writing the Technical Report," by J. Raleigh Nelson, McGraw-Hill Book Company, Inc., New York, 1952.

THE IMPORTANCE OF SELF-EXPRESSION IN ENGINEERING

Engineering is essentially a mental activity, and the results of engineering work are usually in the form of ideas. For example, the result of a year's research work may be a new concept of how heat is transferred through a molten metal. An industrial engineer strives to create a new and satisfactory approach to incentive pay. (You should be able to cite similar examples from each of the other engineering functions.)

To be useful, these ideas must be transmitted to others for their consideration or action. The engineer may be called upon to express his ideas while:

Reporting to superiors and to other departments
Discussing instructions received from superiors
Giving orders to subordinates
Arguing for a proposed plan
Writing contracts and specifications
Writing operation and service manuals

Although all these examples involve the communication of intelligence *verbally*, by means of the spoken and written word, the engineer is unique among professional men in that he must be able to express himself *graphically* and *mathematically* as well. Graphical expression means in terms of pictures, charts, or drawings, while mathematical expression refers to the communication of ideas by means of numbers and symbols. These latter modes of expression will be discussed in subsequent chapters.

There are three principles which every engineering student should recognize. The first is that skill in communication is important. The second is that in seeking an engineering education, the importance of skill in communication should be emphasized. The third is that the importance of skill in communication cannot be emphasized too strongly.

From today on, through 4 years or more of engineering training and throughout your entire engineering career, you are going to translate the output of your mind into usable form. For some of you the process of expression will be a bottleneck, restricting and distorting your mental efforts. For the more fortunate of you, the process will be a filter, rectifying and clarifying and enhancing your ideas.

You should realize that every assignment and every examination is a report to your instructor to demonstrate your progress along the lines of his instruction. In the same way each oral and written report to your superior will be a manifestation of your thinking ability. In many cases your promotion or assignment to a position of increased responsibility will be decided by an executive whose knowledge of your ability is gained primarily from your written reports.

DEFINITION OF A REPORT

The word "report" means to "carry back," to bring back information about something seen or investigated. So the engineering report, oral or written, is a means for making available to the listener or reader information in which he is interested and, frequently, which he has requested. Implied in this statement are three characteristics of a report: it is a form of what is called expository writing, it is written for a definite purpose, and it must be in a form suitable to the reader.

A Form of Exposition

In contrast to other forms of writing such as description, narration, or argumentation, exposition is the setting forth of ideas or facts in the most revealing manner possible. Just as the exhibits at a "world exposition" are carefully and systematically organized to present information about products, so the portions of a report should be planned to make the transfer of ideas easy. In the "whodunit," the writer seeks to mystify and confuse the reader until, in the final courtroom scene, all is disclosed. In the report, however, the writer strives at all times for clarity.

To achieve clarity, the material in the report must be organized according to a definite plan and accompanied by the necessary explanation and interpretation. The organization must be consistent with the underlying purpose of the report. In addition to presenting the bare facts or ideas, the report must describe equipment or methods used, explain technical aspects or complex relationships, and interpret observations and results.

Designed to Accomplish a Definite Purpose

One distinguishing characteristic of the report is that the information is "carried back" for a reason; usually, the reporter is sent out in the first place because of a need for certain information. That information may be needed in making a decision—for example, a report on the desirability of changing over from direct-current power to alternating-current power. Or it may contribute to a critical evaluation of an operation—possibly a report on the annual cost of operation of a metropolitan water system. Or it may be in the form of a request for action on a proposal—why the manual filler control should be replaced by an automatic unit.

Engineering design consists of starting with the specified end result and working backward. The engineer designing a portable radio receiver, for example, starts with a set of specifications in terms of desired output in "volume" and "tone" and limitations on weight and cost. To handle the desired signal output and frequency response requires a certain type of speaker which must be fed by a suitable audio amplifier. This in turn dictates the power supply required and so on back through the detector circuit and the radio-frequency amplifier clear back to the antenna and the input signal. In exactly the same way, the designer of a report must start with the desired end result and select the components and methods of presentation which will accomplish that purpose best.

Designed to Meet the Requirements of the Reader

Throughout the planning of the report the characteristics of the reader must be kept in mind. A newspaper story or a magazine article must be designed for the general public with eye-catching headlines and suggestive pictures. In contrast, the report is written for a particular reader or small group of readers whose requirements are known.

The characteristics of the reader will determine the length, technical level, and plan of the report. The busy executive demands from his technical assistants brief, concise reports with a minimum of detail, whereas the Board of Supervisors requires of its consultants on mass transportation a complete discussion of technical, economic, social, and legal aspects which may take thousands of pages. A report to the chief development engineer can be on a scientific level; the plant operator will be interested in technical aspects and can understand technical terminology which would be avoided in a report to a city council. The plan also will be dictated by the characteristics of the reader and the desired result, with the particular approach and sequence of topics carefully selected.

PROCEDURE IN WRITING A REPORT

So far we have discussed why reports are important in engineering and what is to be accomplished in a report, but just how do you go about writing a good report? Fortunately, it is not so difficult as you might think. The procedure recommended here consists of four distinct and separate steps: studying, designing, writing, and checking.

Study the Material

Usually a report is written after some engineering work and is based on information gathered by observation, investigation, measurement, or experimentation. The first step consists of assembling, sorting, and appraising the available information and data. There may be some calculations, graphs, pictures, tabulated data, observations, expert opinions, or some other reports on the same subject. What do the data indicate? What do you have to tell? Is your information adequate, or do you need additional data? Until the answers to these questions are clearly in your mind, no attempt should be made to begin the second step.

Design the Report

Now comes the planning. What is the purpose to be accomplished in the report? What are the limitations on your discussion, or what is the precise subject? What is your viewpoint on this matter? What are the characteristics of the reader, and how will these affect the handling of the report? The answers to these questions indicate the strategy to be followed in presenting the available information in order to accomplish the desired objective. There is a close analogy to military strategy in which the available men and weapons must be distributed and their advances timed to accomplish a given objective with a minimum loss.

This design stage is probably the most important of all, and it merits considerable time and effort because it is the quality of the design that determines the quality of the report. It is important that the design be complete before you do any writing. Nelson suggests two conclusive tests of progress, the "thesis sentence" and the "outline plan."

The thesis sentence is a brief statement of just what you have to say; it is the "message" which you have to report. For example, the thesis sentence for this chapter might be: "The oral and written reports, which are so important in engineering, should be designed to accomplish a definite purpose and to meet the reader's requirements."

Until you can write out a single sentence which clearly indicates the precise subject to be presented and your viewpoint on that subject, you are not ready to write. The *subject* is limited to oral and written engineering reports, eliminating, for example, poems. The *viewpoint* is that "reports . . . should be designed." There is also a hint of the *plan* of the chapter, first a discussion of why reports are important in engineering and then some training in report design.

The outline plan indicates the structural pattern of the report and is based on an analysis of the material available in terms of the purpose to be accomplished. The outline indicates the important topics, the sequence of topics, and the relationship between major and minor topics. One good approach for you as a beginner is to enter on individual 3- by 5-in. cards the bits of information and data resulting from the investigation. The cards are then spread out on your desk and sorted and shifted, with your thesis sentence always in front of you, until an effective organization of material is obtained. After the cards are arranged to obtain the most logical and strategic plan, you can transfer the topics to a single sheet of paper. The first part of the outline plan for this chapter was as follows:

I. Introduction.
    A. Subject—oral and written engineering reports.
    B. Purpose—to provide motivation for studying English and some preliminary training in report writing.
    C. Plan—as indicated in the outline.

II. The Importance of Self-expression in Engineering.
  A. Engineering work usually results in ideas.
  B. To be useful these ideas must be communicated to others.
  C. The engineer must be able to express his ideas in three ways.
III. Definition of a Report.
  A. A report is a form of exposition.
  B. It is designed to accomplish a definite purpose.
  C. It is designed to meet the requirements of the reader.
IV. Procedure in Writing a Report.
  A. Study the material.
  B. Design the report.
  C. Write the rough draft.
  D. Check the report.

Actually the outline included third-order headings, subheadings 1, 2, and 3 under second-order headings *A*, *B*, and *C*. Check the first part of the chapter against this outline, and then, to see if you understand outlining, write out the outline for the remainder of the chapter.

Write the Rough Draft

Don't begin to write until the design is complete—until you have a thesis sentence and an effective structural plan. Once you start to write, emphasize production—getting your ideas down on paper—and leave criticism of your work until later. If you attempt to perfect each sentence as you go along, you will interrupt the smooth flow of ideas which is so important in a good report.

Another way of getting a smooth flow of ideas is to write a relatively large section at one sitting with no interruptions; this will tend to produce coherence—the ideas will hang together. Some of you will be able to write rapidly *and* well, but this usually takes years of practice.

Check the Report

The rough draft must be checked against the design, and it must be compared with high standards of composition. To determine if the design has been carried out, you should ask yourself such questions as: Does it accomplish the stated purpose? Does it meet the particular needs of the reader? Does it stay within the limitations of the subject?

The first draft of a beginner will probably be pretty rough, but if it is unified and structurally sound and if the ideas flow smoothly, the final polish is not difficult. Is it free from distracting mistakes in grammar, word usage, punctuation, and spelling? Are the sentences strong, clear, and effective? Are the paragraphs consistent and coherent? Have you kept your standards high? If so, you and the reader (possibly your employer) will be well pleased with the result.

GENERAL ORGANIZATION OF A REPORT

In setting up an exhibit at an exposition, every effort is made by the exhibitor to make it easy for the viewer to gain an understanding of the display. So in a report, the test of every part is: Does this help the reader? There are certain standard methods of helping the reader in the introduction, the body, and the terminal section.

The Introduction

The introduction is a preliminary conference between the reader and the writer. In a sense you say to the reader: "Before we get into the main part of the report, I am going to indicate just what the report is about, explain what my attitude is toward the subject, and point out how I am going to present the material." In general the introduction should include the *subject*, the *purpose* or *viewpoint*, and the *plan*. If you define the limits of the discussion, the reader will not be disappointed or critical if certain aspects of interest to him are not discussed. If, before he gets into the detailed discussion, the reader has a picture of the plan to be followed, he will not get lost. If he has a clear idea of what you want him to get out of the report, the reader will be looking for your points and they will get his full attention.

The Body of the Report

Working from the previously designed structural plan, each topic heading from the outline is translated into a section of the report. Paragraphs can be introduced by "topic sentences," which are then amplified and explained in the remainder of the paragraphs. In a sense, the writing consists of hanging meat on the skeleton.

To help the reader, the writer should make clear the change in thought represented by a new section and, at the same time, he should indicate how the new material is related to what has gone before. The phrases and sections which serve this purpose are called "transition" material. The paragraph on page 186, beginning "So far . . . " and ending " . . . and checking" is a transition section. How does it indicate the beginning of a new topic? How does it relate the new material to what has gone before?

Another way to help the reader is by using section headings. These are used in textbooks and magazine articles as well as in reports because they can be read at a glance and the reader knows just what is the topic under consideration. Frequently the outline plan can be converted into a schedule of section headings, although rewording is usually desirable.

The Terminal Section

The longer the report, the more attention should be given to keeping the reader informed as to what the next topic is to be and how it is related

625 North Fifth Street
Cucamonga, California
April 15, 19__

Acme Electronics, Inc.
7354 Cranshire Blvd.
Los Angeles 23, California

Attention: Mr. David Michael, Personnel Manager

Dear Mr. Michael:

I am just completing my second year at California State College as an electronic engineering major, and I am interested in obtaining summer employment with your company. Perhaps my background of experience and training would make me a useful temporary employee.

Four years ago I became interested in radio and joined my high school radio club. I soon obtained my amateur license and have been active as a "ham" ever since. I built and operated my own equipment and repaired radio and television sets for my family and friends to finance my hobby. However, I found I was more interested in the engineering aspects of electronics and therefore decided to obtain college training. So far I have completed courses in mathematics, physics, and chemistry--all with grades of B or better. The work is very interesting, especially the electrical part of physics, but I am anxious to obtain more practical experience.

The quality of Acme products is well known among radio amateurs, and employment with your company would provide an excellent opportunity to learn what is behind a good product. I realize that my background would fit me for only a routine test or assembly job, but I believe that you would be pleased with my work in such a position. I will be in Los Angeles on Thursday, April 30, and would appreciate an interview at a time convenient for you.

Sincerely yours,
Craig Byron
Craig Byron

EXAMPLE A: The business letter is a special type of report following a conventional form. Note in this application for employment the three paragraphs representing introduction, body, and terminal section. Even in this brief introduction, the "subject," "purpose," and "plan" are indicated.

CINCINNATI POWER PRODUCTS CO.

Interoffice Memorandum

DATE: September 1, 19--

TO: Dan Jeffrey, Chief Inspector

FROM: Kent Warner, Engineering Department

SUBJECT: Chain Failure Study and Recommendation

In accordance with your telephoned request of August 30, we have inspected the broken chain which caused the accident in the steel warehouse last week. This chain apparently failed as a result of progressive embrittlement, and a slight change in our inspection and maintenance procedures should prevent any further trouble.

These chains are made of a high-grade wrought iron which because of its extreme ductility will stretch considerably under overload. This provides a shock-absorbing capacity and also some visual warning of overload. Because of overstraining or owing to the peening action of the links on each other, chains tend to become brittle with use and sudden failure may occur. Periodic annealing under proper conditions will eliminate this brittleness. For example, this $\frac{3}{8}$-inch chain should be annealed in a temperature-controlled furnace at 1350°F for 15 minutes.

We recommend that your inspectors be instructed to examine all chains for evidence of work-hardening or overstrain and that any chains showing signs of possible brittleness be removed from service for annealing.

EXAMPLE B: The memorandum is a modified form of short report which is used frequently in business and industry. It resembles the letter, except that the salutation and complimentary close are omitted and a standardized heading is used. The elements of a good report should be retained although in abbreviated form. The "subject" is stated clearly and completely, and the "viewpoint" or "purpose" indicated; the "plan" may not be necessary in a short "memo." The necessity for careful organization of a short report was emphasized by the writer who said, "Please excuse this long letter; I did not have time to write a short one."

to what has gone before and what is coming later. However, it is not possible for the reader to keep all the points in mind as he reads through the report. The terminal section serves as a final conference with the reader in which the writer can bring the discussion to a proper close consistent with his original purpose as indicated in the introduction.

The terminal section serves to bring the essential material into focus in a single section and to make sure that the reader gets the essential idea. The human mind is limited in the number of ideas which it can grasp at one time; there are indications that the maximum number is around five to seven. Certainly no one can keep clearly in mind 30 different aspects of a problem. There is also a limit to the quantity of material you can retain in mental focus, probably something less than a page. As you read through a multipage report or a chapter in a textbook, early points fade into the background as additional ideas take their places. The terminal section provides an opportunity to create the most desirable final impression.

The terminal section takes on different forms depending on the purpose of the report. A *summary* is a restatement of the important points with the mass of detail omitted; it usually parallels the presentation in the report. A *recommendation* consists of suggestions for action based on the discussion and may include a brief statement of the reason for each recommendation. In a *conclusion* the writer draws conclusions from the evidence submitted in the body of the report; no new ideas should be introduced in the terminal section.

What is the most appropriate type of terminal section for this chapter? Referring to the introduction it is seen that the purpose was to provide motivation for studying verbal expression and to give some preliminary training in report writing. In line with that purpose, probably a brief summary would be the most effective way to close this section.

SUMMARY

The results of most engineering work are in the form of ideas which become useful only when they are communicated to others. You may find that your engineering ability will be measured in terms of your ability in self-expression, and your entire career may be dependent upon your skill in making oral and written reports. College is the best place to develop that skill.

A report is a form of exposition which has been designed to accomplish a definite purpose and to meet the requirements of a particular reader. The preparation of a report can be accomplished in four separate steps. First, the material should be studied until you are sure that you know what you have to tell and that your data are adequate. Next the report must be designed to accomplish the desired objective; working from a thesis sentence, you should develop a strong structural plan. The third step is writing, which should not be started until the design is complete. Once you start to write, emphasize production and leave criticism of your work until later. Finally, check the rough draft to see that it does what it was supposed to do and that it meets high standards of composition.

Throughout the entire report—the introduction, the body, and the terminal section—make every effort to keep the reader informed on what you are doing and why, so that when he finishes the last sentence, he has obtained the full benefit of your work and your thinking. In all your writing, keep your standards high; you will never exceed them.

ASSIGNMENTS

12-1. List three specific reasons why ability in verbal expression is important for engineers.

12-2. Study an engineering report or a magazine article based directly on a report. Cite the title, author, and source and answer the following questions:

a. In what respects is the report an example of "exposition"?

b. What is the definite "purpose" for which the report was designed?

c. What are the characteristics of the reader for whom the report was written?

12-3. Considering Chap. 9 as a report, write a thesis sentence and prepare an outline plan.

12-4. Considering Chap. 11 as a report, write a thesis sentence and prepare an outline plan.

12-5. Considering Chap. 6 as a report, what paragraphs constitute the introduction? What words or phrases indicate the "subject" of the report? The "viewpoint"? The "plan"?

12-6. Considering Chap. 7 as a report, what paragraphs constitute the introduction? What words or phrases indicate the "subject" of the report? The "purpose"? The "plan"?

12-7. Assume that you are an application engineer recommending one of your company's products to a customer who is considering an entirely different product. Write a one-page report designed to convince your customer (who is a nontechnical man) of the advantages of your product. Submit a thesis sentence and an outline plan along with your report.

12-8. Assume that you are an engineer who has just returned from an exposition at which you saw displayed a new device which might be applied in your plant. Write a one-page memorandum to your boss describing the operation of the device, pointing out how it could be applied, and making a specific recommendation. Submit a thesis sentence and an outline plan along with your report.

12-9. Write your instructor a brief report in business-letter form describing your background, explaining how you came to study engineering, and indicating the type of work you hope to do in the future. Follow all the rules of report writing.

13

ENGINEERING DRAWINGS AND GRAPHS

Suppose that you were asked to construct a slotted wedge and given the following instructions: Start with a block of steel 2 by 3 by 4 in., considering one 3- by 4-in. face as the base and one 2- by 4-in. face as the front. From the horizontal center line of the front, make a diagonal cut to the upper edge of the 2- by 4-in. back, removing all the material above the diagonal plane. In the center of the back and starting from the top, cut a rectangular slot $\frac{1}{2}$ in. deep and $\frac{1}{2}$ in. wide with its bottom parallel to the base and its sides parallel to the 2- by 3-in. sides of the original block. Could you do it?

To test your visualizing ability so important in engineering, try to draw a sketch of the wedge approximately to scale. This is all right for an interesting little test, but obviously it would be a poor procedure to follow in the machine shop. If some ancient Chinese had not beaten him to it, we can be sure that the first engineer would have said: "One picture is worth a thousand words," and ever since, engineers have been using pictures to explain their ideas and designs.

Along with verbal and mathematical expression, graphical expression is a necessary tool for the exposition of engineering ideas. The engineer must be skilled in the use of all three media and in the translation of ideas from one medium to another. In the first year of most engineering curricula, the student receives training in the principles and practice of graphical representation, the indispensable and universal language of engineering and industry. Perhaps you are now enrolled in a course in engineering drawing. Throughout the remainder of your college work and in your future work as an engineer you will find frequent use for your skill in graphical expression; develop it to the fullest extent.

Only an introduction to this broad subject can be given here. First the types of drawings and their uses will be discussed, and their similarity to reports will be pointed out. Then the principles of graphical representation will be described and applied to technical sketching. Finally, some training will be provided in the design and preparation of the widely used engineering graph. The important subject of instrumental or "mechanical" drawing has been omitted from this brief treatment of engineering graphics.

THE GRAPHICAL LANGUAGE OF INDUSTRY

Engineering drawings are strictly utilitarian—planned to meet definite needs in the best possible way. In general the graphical language has been developed to record ideas and to transmit instructions. Drawings may be used to tell how something looks, what it is like, how to construct it, how to assemble it, how to connect it up, or how to take it apart. As with a report, in each case the use determines the form and the requirements of the reader must be kept in mind.

What Does It Look Like?

Sometimes it is desirable to show an object as it appears or will appear to the eye. An aerial photograph of a proposed freeway location indicates the nature of the buildings which will have to be removed. An architect's colored rendering gives the owner an idea of how the proposed building will look when painted and fully landscaped.

Architect's Sketch

An architect's rendering shows how the proposed building will look. (*Higgins and Root, Architects.*)

Note that photography provides a camera's-eye view of a three-dimensional object which is reduced to a two-dimensional picture. We say that the picture represents the "projection" of the object onto a single plane. The same effect can be obtained by an artist using perspective to give an illusion of depth as in the architect's "picture." This so-called "pictorial" drawing is frequently used by engineers to indicate what an object looks like.

What Is It Really Like?

The usual aerial photograph possesses distortions which prevent it from being used quantitatively. While it is possible to make precise maps from the air using the modern methods of photogrammetry, even then only the surface appearance is recorded. The highway engineer needs complete information about topography, elevations, soils, drainage, and other features which can be obtained only by a survey crew on the site. Their observations are recorded on detailed maps drawn to scale with data indicated symbolically. For the engineer, such a map provides the best picture of what the terrain is really like.

How Is It Made?

While the architect's rendering pleases the owner, it is of no use to the builder. He needs precise measurements and detailed instructions. Unusual features such as a spiral staircase must be drawn to scale with full specifications on materials and finish. Standard elements such as framing members or electrical outlets may be indicated symbolically. The important thing is that the drawings satisfy the requirements of the user—accepted convention wherever possible and complete details when necessary.

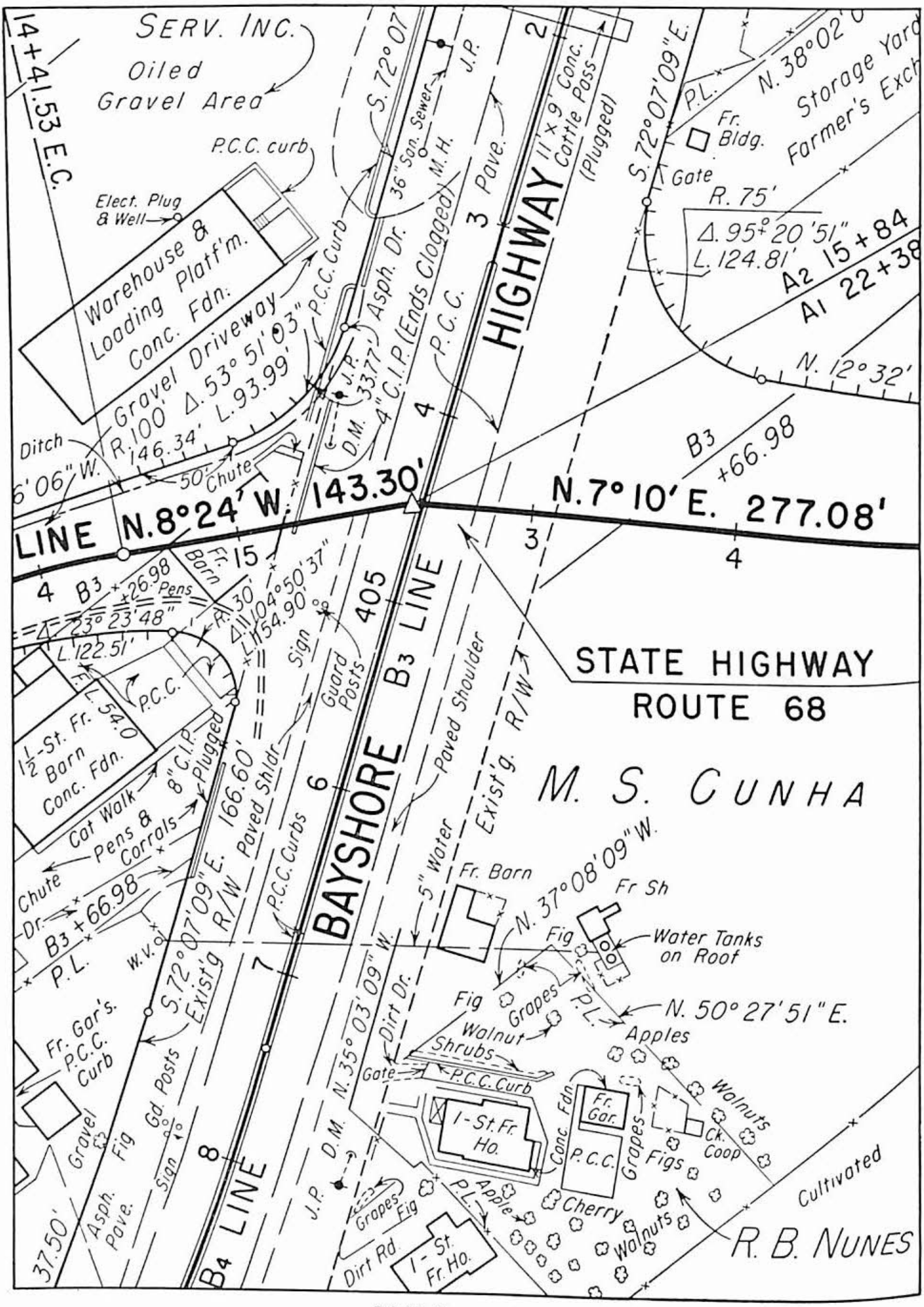
The working drawings sent to the shop must be easily read and unequivocal; parts constructed in the local shop must fit those produced in another shop hundreds of miles away and have the same finish and appearance. The drawings indicate the materials and tools to be used, show precise dimensions and locations of components such as projections and holes, and specify the finish to be produced. The best shop drawing results in the production of a satisfactory part with a minimum of material, labor, and time.

How Is It Put Together?

Usually a separate assembly drawing is made to indicate how the various parts go together in the complete unit. The assembly drawing may show just the external features of the component parts, or it may, by means of section views, indicate internal features as well.

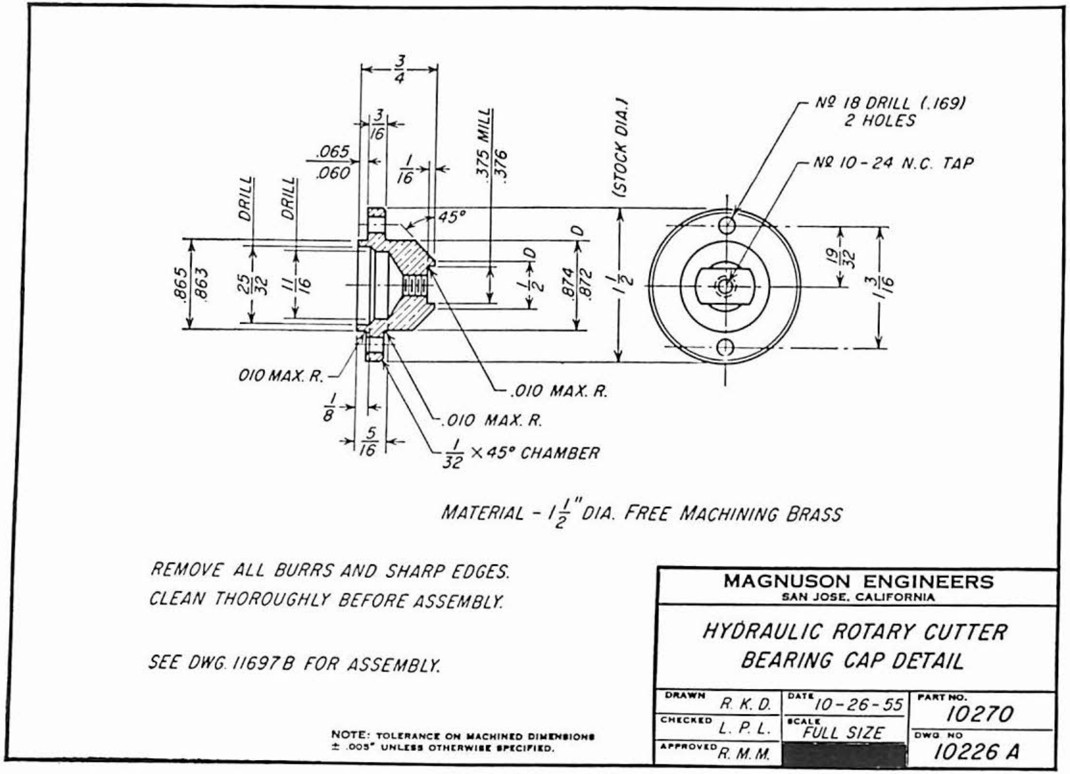
The assembly type of drawing is frequently used by the design engineer to indicate how a device works and the functions of the components; certain critical dimensions may be shown. Novel features will be shown in great detail, but standard parts will be indicated by symbols only.

In the drawings used for guiding the assembly of complex units, only the information needed to show the relationship of the parts is shown. The individual parts are not dimensioned, but clearances and distances between centers are given. Section views are used to indicate how one



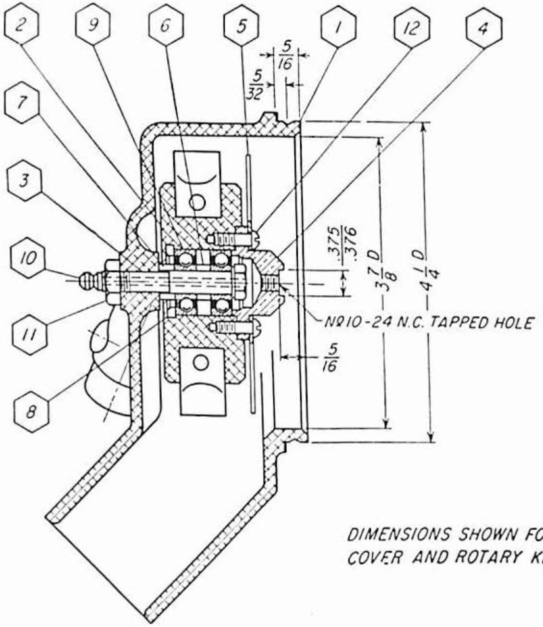
Field Survey Map

A field survey map provides detailed information required by the highway engineer.



Detail Drawing

A detail drawing shows how a part is to be made.



ITEM	DESCRIPTION	PART Nº	DWG Nº	NO. REQ'D
1	CASE	10258	10211 D	1
2	ROTOR	11621	11756 B	1
3	SHAFT	11616	11745 A	1
4	BEARING CAP	10270	10226 A	1
5	STRIPPER	10274	10230 A	1
6	SPACER	11617	11746 A	1
7	SPACER	11618	11746 A	1
8	SEAL	11619	11747 A	1
9	BALL BEARING - NEW DEPARTURE Nº 38			2
10	LUBE FITTING - ALEMITE Nº1736			1
11	JAM NUT - $\frac{5''}{16}$-24 N.F. BRASS			1
12	MACHINE SCREW - Nº8-32 N.C.x$\frac{1}{2}$ R.H. BRASS			2

DIMENSIONS SHOWN FOR MOUNTING
COVER AND ROTARY KNIFE.

U.S. PAT. Nº 2,512,921

NOTE: TOLERANCE ON MACHINED DIMENSIONS
± .005" UNLESS OTHERWISE SPECIFIED.

MAGNUSON ENGINEERS
SAN JOSE, CALIFORNIA

HYDRAULIC ROTARY CUTTER
ROTOR AND CASE ASSEMBLY

DRAWN R. K. D.	DATE 10-26-55	PART NO.
CHECKED T. G. C.	SCALE FULL SIZE	DWG. NO 11697 B
APPROVED R. M. M.	[redacted]	

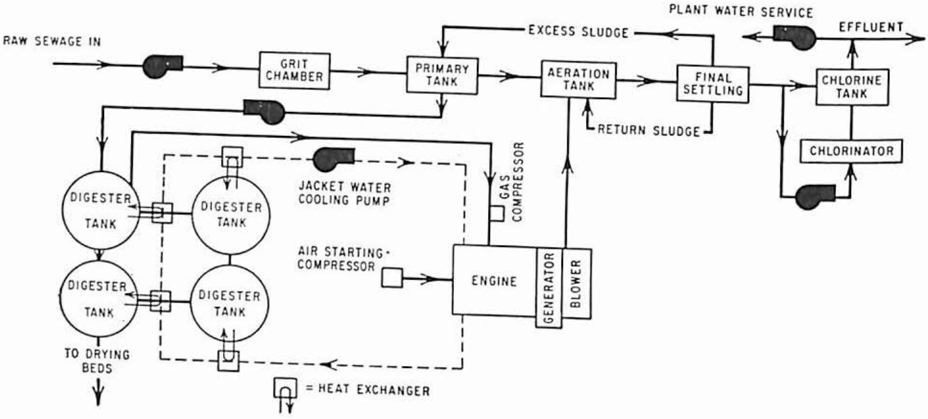
Assembly Drawing

An assembly drawing indicates how the parts go together in the complete unit.

part fits inside another, but the drawing must be kept as simple as possible to avoid confusing the assembler. Sometimes the so-called "exploded drawing" is used to help the person who is not trained to read engineering drawings. The parts are usually numbered in the order they are handled by the assembler.

How Is It Connected Up?

The installation assembly and diagrammatic drawings have special applications in piping and wiring. The piping drawing may be semi-pictorial, showing the external contours of pumps, piping, valves, etc., or it may be a single-line diagram with units indicated symbolically. This type of drawing is used in erection or installation, and the only dimensions shown will be those needed for locating the individual components or for showing over-all sizes.



Diagrammatic Drawing

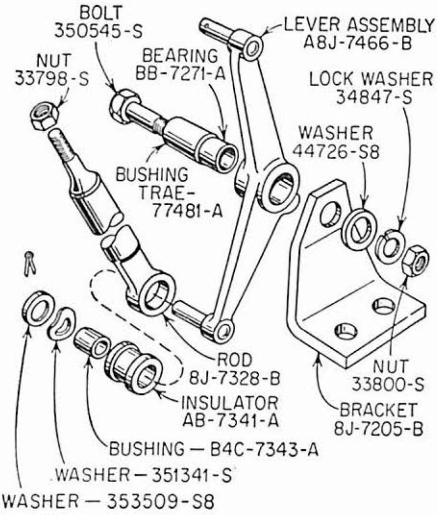
A diagrammatic drawing shows process operation by means of conventional symbols. (*Worthington Corporation.*)

Electrical circuits are always shown diagrammatically with conventional symbols for resistors, motors, contactors, vacuum tubes, etc. Such a "schematic" diagram is designed for clarity, and no attempt is made to indicate location or size. The "flow" diagrams used in chemical engineering processes and in plant layout are other examples of diagrammatic drawings.

How Is It Taken Apart?

Whenever a complex device is manufactured, special instruction sheets must be prepared to guide those concerned with its operation and maintenance. These instructions range in length from a few lines on a card for a garden sprayer to several large volumes for a military plane. In explaining the operation and maintenance procedures, clear drawings are highly effective.

In general, maintenance drawings are similar to installation assemblies; however, special details are shown to guide repairmen. Parts are designated by catalogue number to facilitate ordering, but dimensions and materials are not shown. Details are given on the adjustments which compensate for wear, and the clearances required for proper operation are indicated.



Maintenance Drawing

A maintenance drawing designates parts by catalogue number and indicates installation procedure. (*Ford Motor Co.*)

INDUSTRIAL DRAWING PRACTICE

It was pointed out previously that in pictorial drawings perspective and shading are used to show three-dimensional objects as they look to the eye. However, the "distortion" intentionally introduced in perspective prevents its use in showing accurately the construction of an object. How can three-dimensional objects be shown on two-dimensional paper?

A photograph of a house taken with the camera at a great distance and pointed at right angles to the front of the house will give a fairly accurate representation of the *front* of the house. If the camera is imagined to be at an infinite distance from the object (so that the lines of sight are parallel rather than diverging), if it is pointed at right angles to one plane of the object (so that the lines of sight or *projectors* are perpendicular to the plane), if the camera has an X-ray characteristic (so that hidden details are shown), and if a series of pictures are taken of front, back, top, bottom, and sides, then an accurate representation of the object can be shown on two-dimensional paper.

Multiview Projection

The technical name for this type of drawing is *multiview* or *orthographic* projection. Orthographic means drawing on the basis of points and lines projected at right angles to *planes of projection*. In Fig. 13-1 the front view of the "guide bracket" has been projected on to a vertical plane. The dashed or *hidden* lines (3 to 4) show the contours of the hole which are not visible from the front. In this view, points 5 and 6 appear at the same point, similarly with points 7, 8, and 9. The relative location of these points should be shown in a top view obtained by projecting features of the bracket upward onto a horizontal plane. Can you visualize how this would appear?

In Fig. 13-2 the bracket is seen surrounded by a transparent box. The projections are drawn to indicate front, top, and right-side views. If the box is considered to be formed by folding a flat sheet of paper, unfolding the paper will result in the six sides shown in Fig. 13-3. The six views are shown in the standard positions. Note that the bottom, left-side, and back views duplicate the information provided by the top, right-side, and front views. In most cases the combination of three views shown in Fig. 13-4 is the most useful.

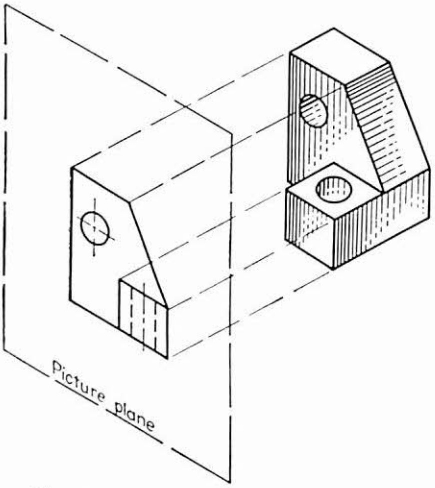


FIG. 13-1. Orthographic projection.

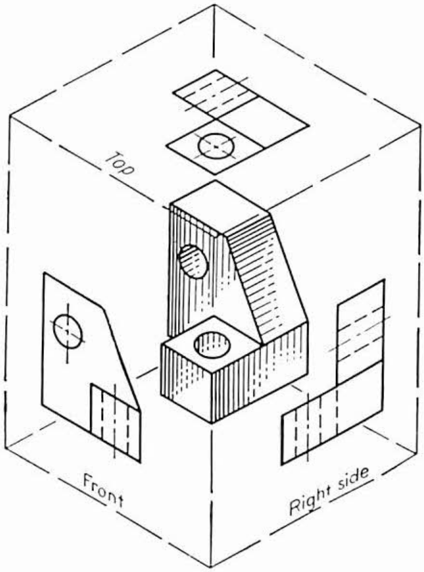


FIG. 13-2. Object in a transparent box.

In selecting the views to be shown, the front view (assumed to be in the plane of the paper) should show the most characteristic shape of the object or show its natural appearance when it is in its normal position. The other views are assumed to be rotated into the plane of the paper as if the sides of the transparent box were hinged. The top view is always located above the front view and is related to it by direct projection. The right-side view is always located to the right of the front view and projected from it.

Occasionally only two views will be necessary, for example if the sections are rectangular, circular, or symmetrical (see Fig. 13-5). Additional

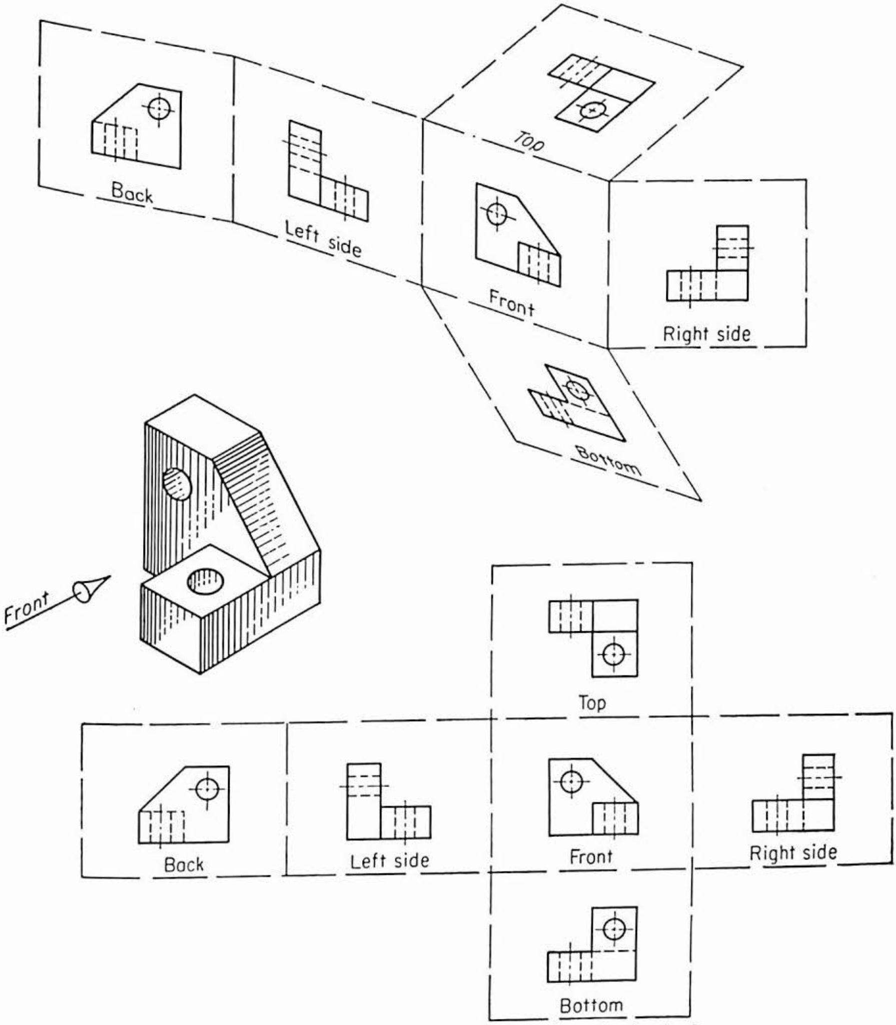


FIG. 13-3. Relative positions of the six principal views.

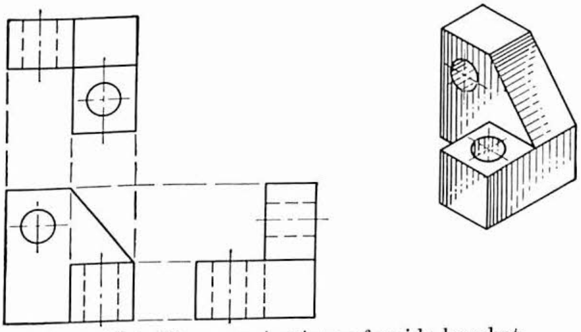


FIG. 13-4. Three projections of guide bracket.

projections called *auxiliary views* may be necessary if the regular views do not make clear all the details of construction (see Fig. 13-6). The interiors of parts can be shown to advantage by *sectioning*, drawing a view showing a part of the object cut away. In Fig. 13-7, the line *AA* represents a cutting plane giving the full section, which is much clearer than the usual front view.

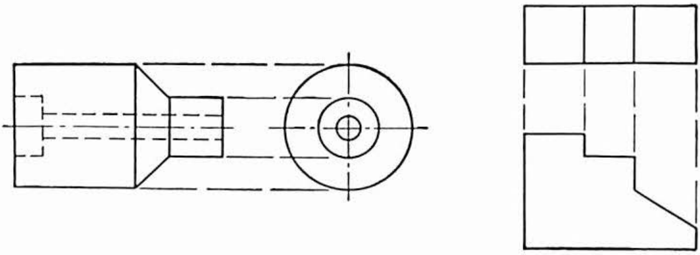


FIG. 13-5. Two-view drawings of symmetrical objects.

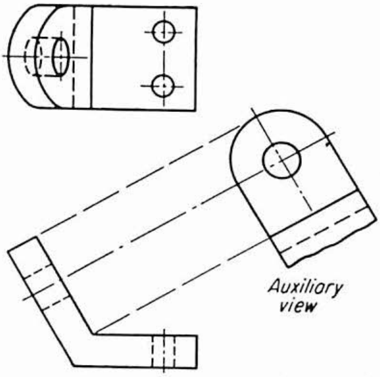


FIG. 13-6. Auxiliary view of inclined part.

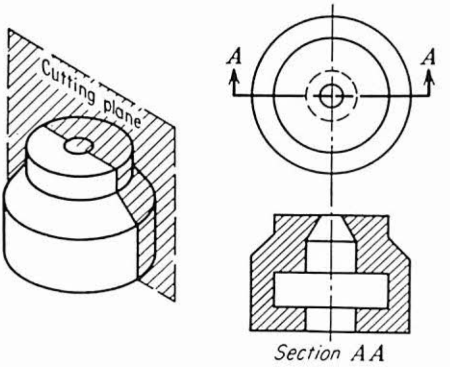


FIG. 13-7. Section view showing interior.

PICTORIAL DRAWING

A photograph provides a two-dimensional picture of a three-dimensional object by introducing a type of distortion called *perspective*. It is perspective which makes a more distant object appear smaller. The far corner of the building in Fig. 13-8 appears shorter than the closer corner. The horizontal lines, which in reality are parallel, appear to converge at a point in the distance called the vanishing point (VP).

Perspective

The apparent shortening of vertical lines and converging of parallel horizontal lines is due to the fact that the angle subtended at the eye by a given length decreases with distance from the eye (or camera). In Fig.

13-9 it is seen that when the lines of sight are projected onto a *picture plane* (PP), the near corner is projected as a length AA while the far corner is shown as the shorter distance BB.

Perspective views are developed from the regular views of orthographic projection. While such views are valuable when natural appearance is desired, the fact that the lines are drawn converging rather than parallel makes perspective drawing difficult and time consuming. Many of the advantages of perspective drawing can be obtained by other forms of pictorial drawing which are much easier to prepare, for example *isometric* and *oblique* drawings.

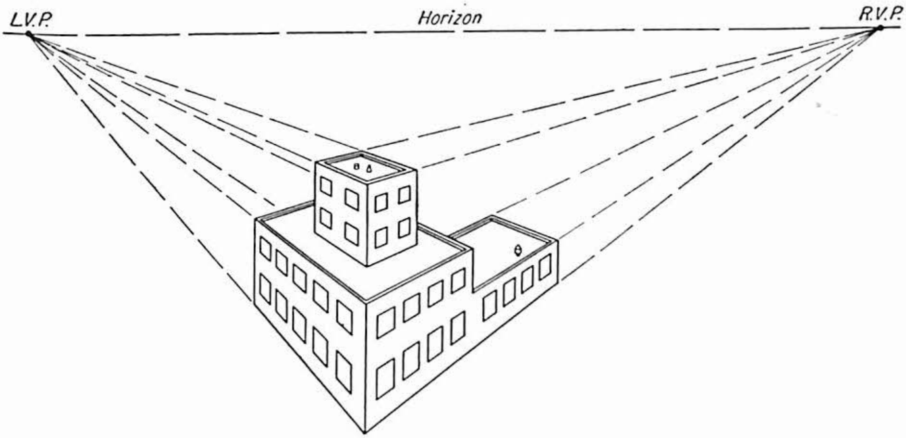


FIG. 13-8. Perspective drawing.

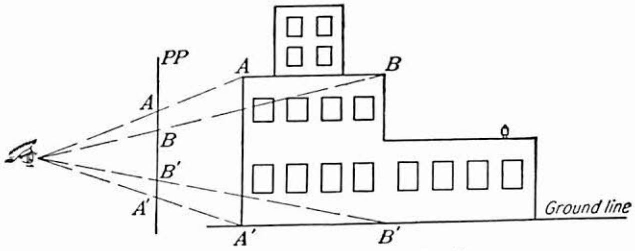


FIG. 13-9. Perspective projection.

Isometric

The illusion of depth in a drawing can be obtained by placing the object so that more than one surface is visible. In Fig. 13-10 the shoe box has been tilted until lines OA, OB, and OC make equal angles with the plane of projection (the paper). These lines would be shortened by about 20 per cent in the isometric projection, but in an isometric *drawing*, the draftsman neglects this proportional reduction and draws all lines full length.

The method of constructing an isometric drawing is indicated in Fig. 13-11. The object is visualized inside an enclosing box, and all measurements must be made parallel to the edges of the box. Note that a circle in isometric appears as an ellipse. The construction of a true projection of a circle is time consuming, and therefore an approximate construction is usually made.*

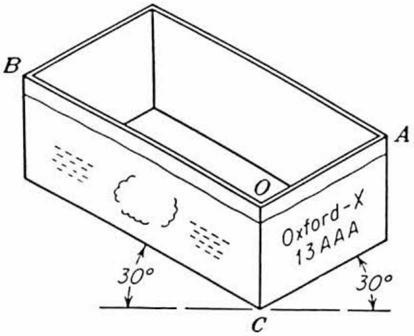


Fig. 13-10. Isometric projection.

Oblique

Isometric drawing provides the natural appearance of perspective without the necessity for a system of converging lines. However, even in isometric drawings all surfaces are distorted because the axes and planes are tilted with respect to the plane of the paper. From the designer's point of view, it would be convenient if at least one face of an object could be shown in its true size and shape and still retain the advantage of a pictorial representation. *Oblique* drawings provide such a combination of advantages.

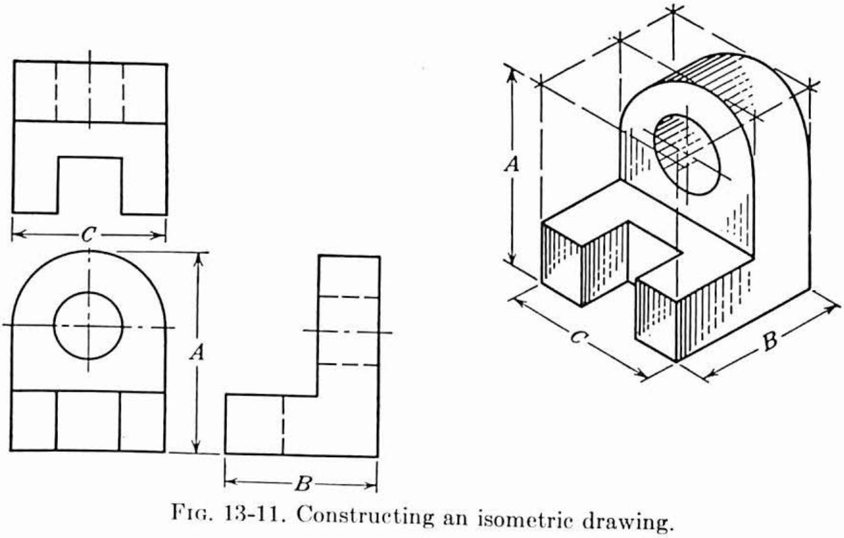


Fig. 13-11. Constructing an isometric drawing.

In an oblique drawing, surfaces parallel to the plane of the paper are projected in true size and shape. Two of the three major axes are perpendicular to each other and indicate width and height in the plane of the drawing. The third axis, indicating depth, is drawn as a *receding line*, usually at an angle of 30 or 45° with the horizontal. In Fig. 13-12 note that dimensions A and C (height and width) are laid off at right angles, whereas dimension B (depth) is laid off along a receding line at an angle of 30°. To increase the sense of realism, the receding measurements may be reduced to give the appearance expected by the viewer; in Fig. 13-13 a depth scale of one-half has been used.

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* See Thomas E. French and Charles J. Vierck, "A Manual of Engineering Drawing for Students and Draftsmen," 8th ed., p. 84. McGraw-Hill Book Company, Inc., 1953.

To realize the advantages of oblique drawing, the front plane must be selected carefully. If the object to be drawn includes circular holes, contours, or irregular curves, the plane containing these should be placed parallel to the paper so that these can be drawn in their true size and shape. This principle was applied in Fig. 13-12. Another rule is that the surface showing the most characteristic appearance of the object should be drawn in the plane of true dimensions. If there is a choice, the long dimension of the object should lie in the plane of the paper to avoid giving the appearance of excessive distortion.

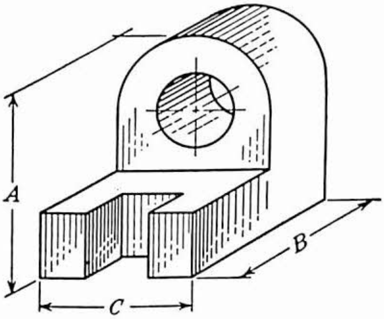


FIG. 13-12. Oblique drawing.

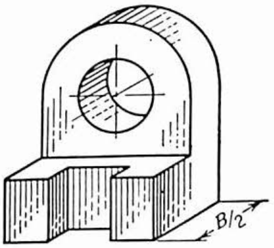


FIG. 13-13. Reduced depth scale.

Industrial-drawing procedures are the result of a long and continuing search for the best means of communicating ideas by graphical methods. The different types of projection discussed here have stood the test of time. Each possesses certain advantages in certain situations, and the young engineer should strive for an understanding of the capabilities and limitations of each. The same principles of graphical expression are applied in the rough sketch made in the shop and the finished ink drawing made with precise instruments.

TECHNICAL SKETCHING

It was pointed out earlier that ideas originate in the mind and to be useful they must be communicated to others. Many engineering ideas are first expressed in the form of freehand pencil sketches. Over and over again the engineer is called on to portray his ideas for his supervisor's review or to indicate what he wishes a draftsman to show or a technician to build. He sketches the features of a device he is working on as an aid in performing related calculations; while in the field he makes a quick map for use when he returns to the office. Skill in sketching will pay off manyfold the small amount of time required to develop it.

The word "sketch" as applied in engineering drawing has two slightly different meanings. In one sense, any freehand drawing is called a sketch regardless of the amount of detail shown; in that sense, complete working drawings are called sketches if drawn without instruments. The other use of the word is in connection with any rough, quick, incomplete, unfinished drawing; in this sense, a straightedge and compass could be used to show quickly and roughly the principal parts of a device under discussion. In general, however, sketching refers to freehand drawing, and the purpose of this section is to point out the desirable tools, techniques, and procedures.

Sketching Tools

Pencil and paper are all that are necessary for satisfactory freehand drawing, and the fact that no special equipment is required adds to the value of sketching as a means of expression. The young engineer will find his work easier, however, if he has two pencils instead of one, paper that is lightly ruled in small squares instead of plain, a soft rubber eraser to remove undesirable lines or smudges, and a sandpaper pad to keep the pencils sharp. A 2H pencil is good for preliminary sketching, and an HB for darkening final lines. If only one pencil is used, an F is a good compromise. A pad of 8½- by 11-in. paper ruled in ⅛- or ¼-in. squares aids in producing straight lines to a reasonably accurate scale. Individual pieces of paper on a clipboard will work just as well.

Techniques of Line Drawing

The pencil should be held gently, about an inch and a half from the point, in a nearly vertical plane and inclined slightly in the direction of motion. The easiest way to sketch a straight line is to use a full-arm movement from left to right. The ends of the desired line can be marked by dots, and a trial swing or two can be made with the pencil just above the paper. When the motion feels right, touch pencil to paper and make a very light line. If it is satisfactory, it can be darkened then or later. If it is unsatisfactory, try again, erasing only when necessary.

It is not to be expected that the freehand line will rival a ruled line; the important things are that it go in the right direction, be the right length, and be essentially straight. Minor wavering is not important. All straight lines, horizontal, vertical, or inclined, may be drawn with horizontal strokes by simply turning the paper. After a little practice, short vertical and inclined lines can be drawn satisfactorily straight, and more quickly, without turning the paper. Long lines can be drawn in a series of short sections.

Circles may be sketched by first drawing light horizontal and vertical lines through the desired center and then marking off the radius along

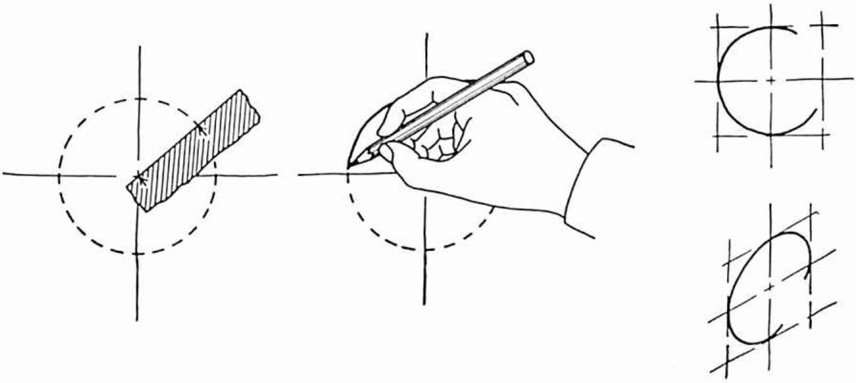


FIG. 13-14. Sketching circles.

these lines by eye or by means of a scrap of paper on which the radius has been marked (see Fig. 13-14). For large circles additional points may be indicated. First sketch the portion of the circle which seems most natural, and then rotate the paper to bring each arc into the natural position. Circles may also be drawn by first laying out the enclosing square; ellipses may be drawn by first sketching the enclosing rectangle or rhombus.

Techniques of Sketching Objects

In approaching any sketching problem, start with the over-all aspect and add details later. For example, in sketching the floor plan of a house start with the outline of the house and then draw in the rooms rather than adding on one room at a time. In making a pictorial sketch, begin with the enclosing box and, with very light lines, block out smaller boxes enclosing the component parts as in Fig. 13-15. Watch proportions carefully. Then sketch in the circles, contours, and other details. Finally darken the desired object lines to give the finished appearance. Shading may be used, but the beginner should go cautiously to avoid doing more harm than good.

In making an orthographic sketch, the following procedure is recommended. Before starting to draw, mark off a $\frac{1}{2}$-in. border and space for a title block. Then study the object, select the front view which will show its most characteristic shape, and determine what other views will be necessary to describe the object adequately. Next, try to visualize how the selected views will appear on the sheet and how they should be spaced to provide good composition. In sketching, first lightly block in the outlines of the main elements in the front view and in the other views. Then sketch in the details, circles, and contours. Finally, darken the desired lines and add dimensions and notes.

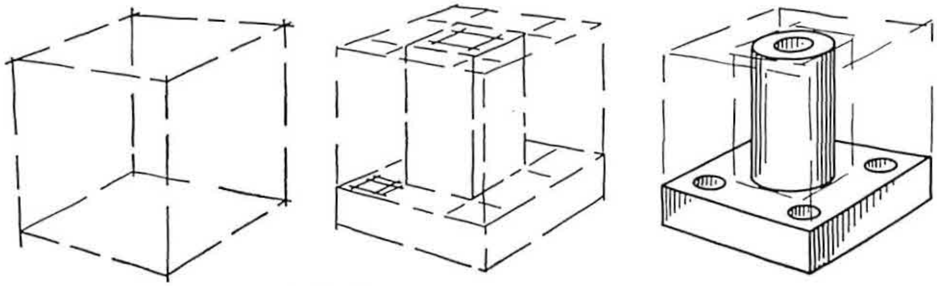


FIG. 13-15. Steps in making a pictorial sketch.

Dimensions and Notes

In developing industrial drawing practice over a long period of time, it has been found that the most effective means of communicating ideas and instructions is a combination of graphical elements (lines and points), numbers (dimensions and quantities), and words (materials and finishes). The graphical portion of the drawings provides the *shape* description, numbers in the form of dimensions and angles provide the *size* description, and lettered notes provide all other necessary information.

Decisions on what should be included and how it should be presented must be based on an analysis of the requirements of the user of the drawings. The rules for dimensioning on a shop drawing are set up to provide the machinist with clear dimensions which can be readily translated into machining operations to turn out parts that meet the designer's specifications and are interchangeable with similar parts produced in some other factory. Some dimensions indicate *sizes* of cylinders, holes, prisms, etc., while other dimensions indicate *locations*—distances from center lines, edges, or other references. Obviously, the dimensions given must be those necessary to make the part and not those necessary to make the drawing.

Information regarding the material to be used, the finish to be achieved, and the fit to be provided between mating parts is included in the form of neatly lettered notes. Special instructions to the patternmaker, the machinist, or the assembler may be included. The location, size, spacing, and even the form of the letters in the notes are carefully selected to provide a maximum of legibility. With practice anyone can learn to letter well; every young engineer should develop sufficient skill so that his sketches and drawings are enhanced by neat and legible lettering.

ENGINEERING GRAPHS

Another important tool of the engineer is the *graph*. Engineering drawings show the relations between points, lines, surfaces, projections, holes, etc., whereas engineering graphs express in visual form the relations between changing quantities called *variables*. Pie charts, bar graphs, and nomograms are other types of graphical presentation which engineers find useful in presenting quantitative information.

Consider the following data which were obtained on a test of an automotive engine with wide-open throttle.

Speed, rpm	Torque, lb-ft	Power, bhp	Fuel consumption, lb/bhp-hr
500	286	27	0.63
1,000	315	60	0.59
1,500	330	94	0.57
2,000	350	134	0.54
2,500	342	163	0.56
3,000	333	190	0.55
3,500	318	212	0.57
4,000	290	221	0.60
4,500	258	221	0.70

Do maximum torque and maximum power occur at the same speed?
What is the torque at a speed of 1,250 rpm?
Is horsepower output directly proportional to speed?
At what speed does minimum fuel consumption occur?
Are all the data of equal accuracy?

Applications of Graphs

Sometimes the answers to these and other questions can be obtained more readily if the relations between the variables are expressed graphically as in Fig. 13-16. Here the pairs of values representing speed and torque, for example, are used to determine points as in analytical geometry. Axes have been laid off, and scales selected. Speed values have been plotted along the horizontal axis, torque values along the vertical axis, assuming a basic relation between torque and speed, or that "torque is a function of speed." The points plotted are representative values, and the smooth curve following the points is drawn as the best estimate of the curve representing the function.

The advantage of a graph over a set of tabulated data is due to the ability of the eye to discern variations in value, slope, and direction. While the tabulated data indicate that the minimum fuel consumption occurs at 2,000 rpm, an examination of the curves throws suspicion on all

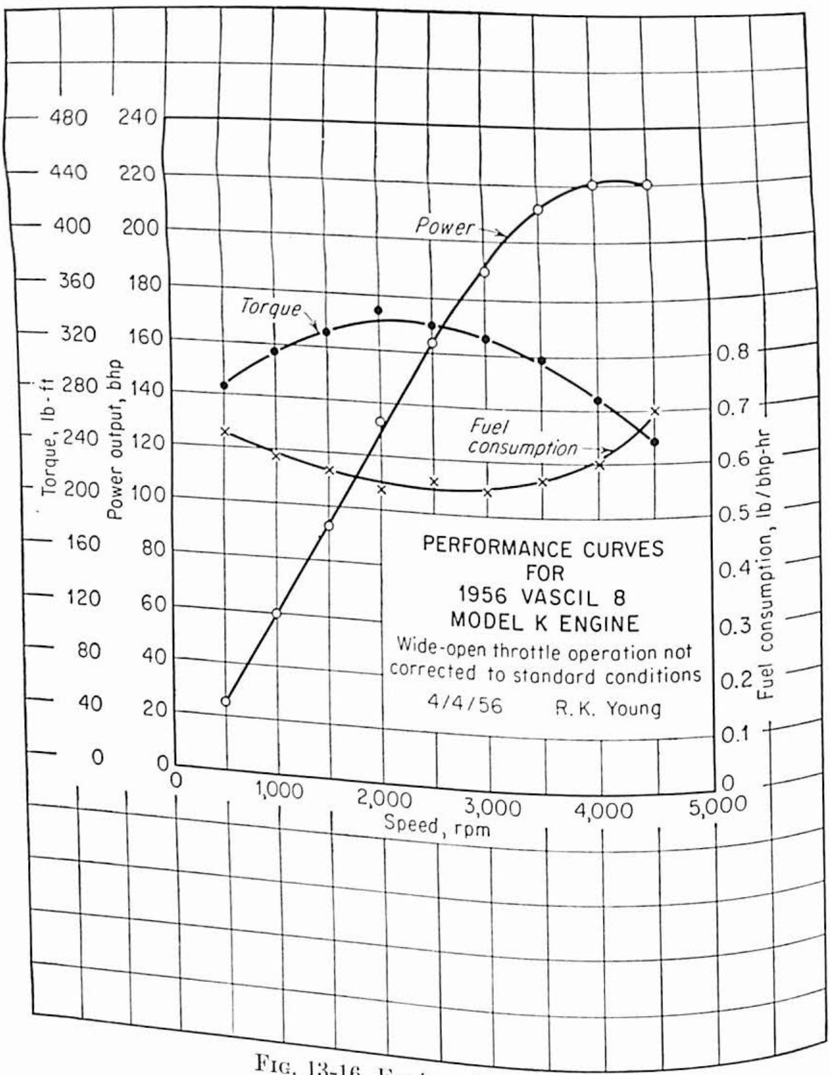


Fig. 13-16. Engineering graph.

the measurements taken at 2,000 rpm. Probably the optimum operating point as far as fuel economy is concerned is near 2,500 rpm. Power output is seen to be nearly proportional to speed up to about 160 hp, but above that point power increases more slowly and seems to reach a maximum at around 4,300 rpm.

Procedure in Plotting Graphs

The rules for plotting graphs reflect the way in which graphs are used. Since graphs are used to present information, the primary emphasis should be on clarity; graphs should be easily understood and quickly read. Frequently graphs or charts which are parts of reports are reproduced and circulated separately, and for that reason they should be self-explanatory. The following general rules incorporate accepted practice.

1. Determine the type of scale which will portray most clearly the functional relation between the variables. With a proportional scale (Fig. 13-16), distances along the axes are directly proportional to values of the variables. Sometimes it is better to plot one variable, or both, on a logarithmic scale. In Fig. 13-17, the logarithmic scale permits plotting a wide range of frequencies and has an additional advantage in that a given percentage change in frequency is represented by the same distance throughout the range.

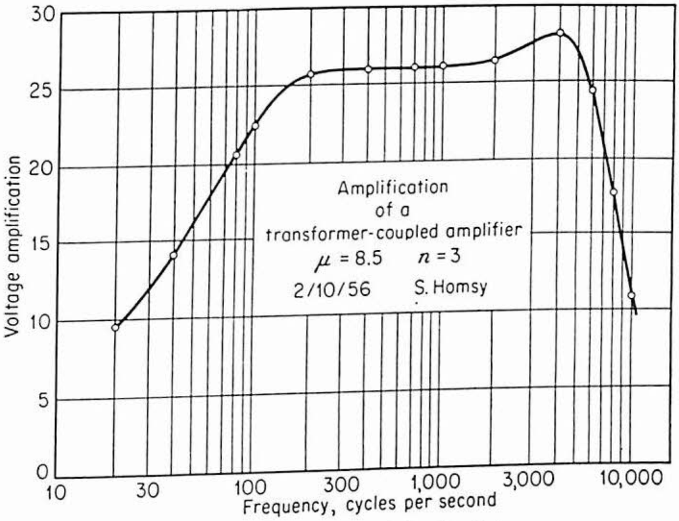


FIG. 13-17. Semilogarithmic plot.

2. Use decimal scales which are easily read and estimated. The multiples of 2, 5, and 10 as found on a slide rule are easy to read, while values of 3 and 7 are hard to work with. To avoid distortion, start all axes from zero unless another origin is required by the function being portrayed.

3. Select a printed graph paper which provides the proper scale and range or carefully prepare your own sheet. Draw the coordinate axes intersecting near the lower left-hand corner of the paper, allowing room for scales, names of the variables and their units, and adequate margins. Plot the independent (controllable) variable on the horizontal axis. Use black or dark blue ink to make reproduction easier.

4. Indicate experimental points by small and distinctive symbols. If there is reason to believe that a continuous relation exists between the variables, draw smooth curves through the test points disregarding minor variations due to experimental errors. Use an irregular curve, lining up the points carefully to get a smooth line. Points on a calibration curve are

connected by straight lines, since there is no basis for assuming a continuous function. Where confusion might arise, distinguish between two or more curves by labeling each curve and by using distinctive lines.

5. Make all curve sheets self-explanatory by including an adequate title. The title should describe the curves and designate the apparatus or unit being tested by make, model, or rating. Indicate any special conditions of test, and include the date and initial or signature of the engineer or draftsman. Observe good engineering form and lettering. Arrange all lettering to read from the bottom or right-hand side of the sheet.

The foregoing are general rules and may be modified in any particular situation. The decision on what procedure to follow should always be based on the answer to this question: How can these data be presented most clearly and most usefully?

RECOMMENDATION

In your contacts with technically trained persons, have you observed their frequent use of graphical expression? Ask an engineer a question about a technical subject, and notice how quickly he picks up a pencil. The engineer who is skillful in presenting his ideas holds a great advantage over the man who lacks that skill. The courses in engineering drawing which you are now taking or soon will take provide you with an opportunity to develop this useful ability. Learn the bases of multiview projection and pictorial drawing, become familiar with industrial drawing practice, develop some skill in technical sketching, and learn to present data graphically. Master the art of graphical expression, along with verbal and mathematical expression, and it will serve you well.

ASSIGNMENTS

13-1. In what fundamental respects do architects' renderings differ from construction drawings?

13-2. In what fundamental respects do working drawings differ from assembly drawings?

13-3. In what fundamental respects do schematic drawings differ from pictorial drawings?

13-4. Given the two views shown in Fig. 13-18*a*, sketch the right-hand view. Repeat for Fig. 13-18*b*.

13-5. Read the drawings in Fig. 13-19*a*, and supply the lines which have been omitted. Repeat for Fig. 13-19*b* and *c*.

13-6. Given the isometric projection in Fig. 13-20*a*, select the most desirable views, plan the spacing on an 8½- by 11-in. sheet, and sketch the necessary orthographic projections. Repeat for Fig. 13-20*b*.

13-7. Given the oblique projections of Fig. 13-21, repeat assignment 13-6.

13-8. Sketch an isometric projection of the item shown in Fig. 13-19*c* (see assignment 13-5).

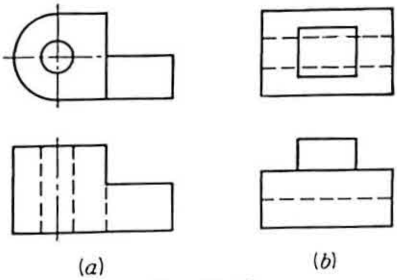

(a) (b)

FIG. 13-18

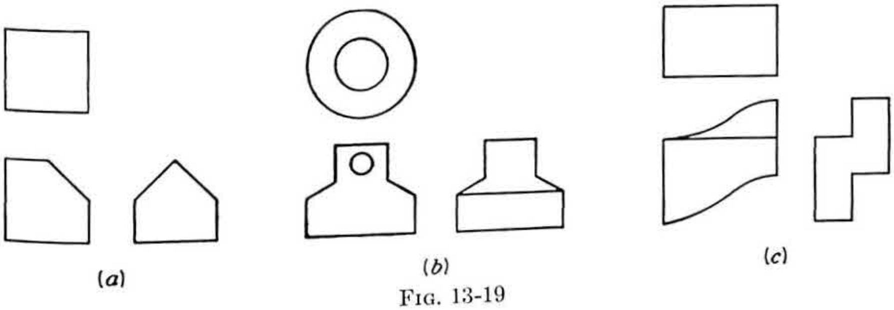
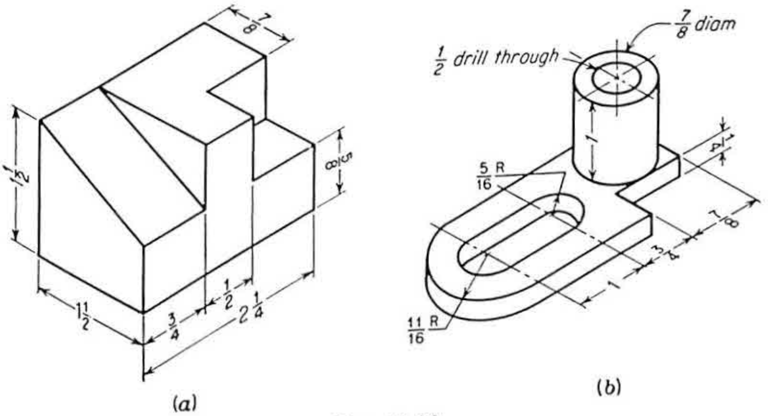

(a) (b) (c)

FIG. 13-19



(a) (b)

FIG. 13-20

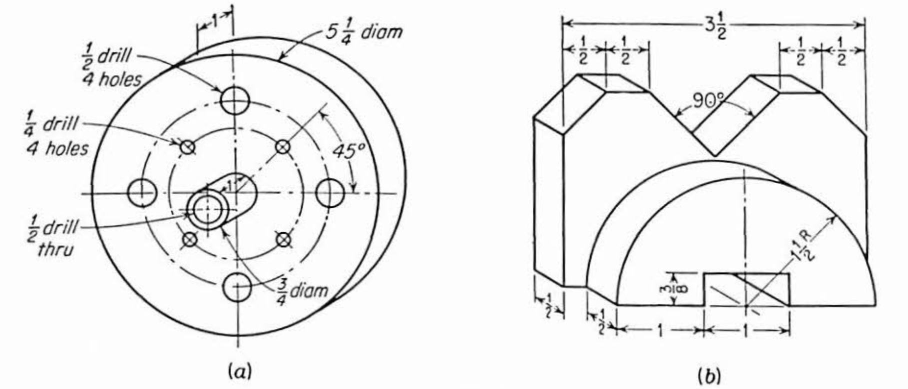
13-9. Sketch an oblique projection of the item shown in Fig. 13-19*b* (see assignment 13-5).

13-10. Sketch from memory the floor plan of your house.

13-11. Look around in one of your school shops or laboratories and select a fairly simple, three-dimensional part which has some curved and some plane surfaces. Make a pictorial sketch of the part.

13-12. Make a pictorial sketch of the slotted wedge described at the beginning of this chapter.

13-13. The following data were obtained by representatives of *Road and Track*



(a) (b)

FIG. 13-21

Magazine while measuring the performance of an Aston-Martin DB-2 six-cylinder sports car.

Time, sec	1.5	3.5	5.0	8.0	9.0	12.0	16.0	20.5	27.0	36.0
Speed, mph	10	20	30	40	50	60	70	80	90	100

Present this information graphically observing all the rules for good engineering graphs

13-14. As an engineer for the Big Push Pump Co. of Garden City, Tex., you have obtained the following data on their new Model 26A 1,200-rpm gear pump.

Pressure, psi	0	50	100	150	200	250
Input power, bhp	4	10	15	22	27	32.5
Efficiency, %	0	65	78	84	86	85

Prepare an engineering graph of these data, using pressure as the independent variable.

13-15. Calibration of instrument 26, an Electrad 100-volt d-c voltmeter Model No. 127A, against the laboratory standard revealed the following:

Electrad voltmeter	10.2	20.2	29.7	40.1	49.5	60.0	70.5	80.6	90.5	100.2
Standard voltmeter	10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	100.0

Prepare a calibration curve for this instrument.

13-16. A fatigue test on samples of chrome-nickel steel which had been oil-quenched and drawn resulted in the data shown. Select appropriate scales and draw a graph of stress vs. cycles to failure.

Repeated stress, psi	Number of cycles to failure
95,000	4×10^4
86,000	5×10^4
75,000	2×10^5
72,000	3×10^5
67,000	1×10^6
67,000	1.2×10^6
66,500	5×10^7
67,000	6×10^7

14

NUMBERS, SYMBOLS, AND MATHEMATICAL TOOLS

It is a matter of common knowledge that increasing the compression ratio of an automobile engine increases the efficiency and therefore tends to reduce the cost of operation. On the other hand higher compression ratios demand fuels with higher octane ratings which are more expensive to manufacture. A knowledge of these general *qualitative* relations is not enough to decide what compression ratio to use. The design engineer must be able to state *quantitatively* the effect on efficiency caused by a specified increase in compression ratio, for example, "a change from 7.0 to 8.5 will increase efficiency by 3.5 per cent." Only when the effects of all the factors have been reduced to quantitative terms can an engineering decision be made. This emphasis on numerical quantities is characteristic of all engineering work and explains why facility in mathematics is so important for engineers.

In addition to working with *numbers*, all scientists and engineers employ *symbols* which represent numerical quantities. One of the major conclusions from Einstein's work was the algebraic equation $E = mc^2$, where E stands for energy, m for mass, and c for the velocity of light, all measured in appropriate units. When a physical relation can be expressed algebraically, then all the powerful *tools* of algebra are available for analyzing and applying the physical principle. The equation $h = \frac{1}{2}gt^2$ expresses the distance traveled h in terms of the acceleration of gravity g and the time t. To find the time required to fall a given distance, the equation can be manipulated algebraically to give $t = \sqrt{2h/g}$.

NUMBERS

Counting is the basis of all numbering systems. We can imagine a prehistoric shepherd keeping track of his sheep by means of a sack of small pebbles—each pebble representing one sheep. Small numbers could be counted out on his fingers. Our present decimal system is based on the fact that we have 10 fingers; actually the word "digit" means "finger."

The Decimal System

In the decimal system a quantity is represented by the value and the position of a digit. Two, two hundred, and one-fifth are all written with the same value in different positions—2, 200, and 0.2. The number 423.54 means

$$\begin{array}{llllll} & 400 & + 20 & + 3 & + \frac{5}{10} & + \frac{4}{100} \\ \text{or} & 4 \times 10^2 & + 2 \times 10^1 & + 3 \times 10^0 & + 5 \times 10^{-1} & + 4 \times 10^{-2} \end{array}$$

In other words 10 is the base and each position to the left or right of the decimal point corresponds to a power of 10, 10 raised to a positive or a negative power.

A New Numbering System

Perhaps it is unfortunate that we do not have 16 fingers because in certain ways 16 would be a much better base for a numbering system. Sixteen is valuable in working with fractions, and it is used already in subdividing the inch. In our numbering system based on 10, 0.1 represents one-tenth, 0.2 represents one-fifth, etc. If our numbering system were based on 16, one-sixteenth of an inch would be written 0.1 in. How would three-eighths be written? New symbols would be needed for 10, 11, 12, 13, 14, and 15. Sixteen would be written "10." What would be the value in decimal terms of the number "100"? Advantages of a base of 16 from the standpoint of the student would include having simpler numbers to work with; for example, the logarithm of 2 to the base 16 is ¼ (which would be written as "0.4"), and the logarithm of 4 to the base 16 is ½ (which would be written "0.8").

The Binary System

A numbering system which is being used a great deal by engineers—the so-called "binary" system—is based on only two numbers. In recording data electrically the simplest system is to indicate whether an electrical impulse exists or not; the corresponding numbers then are "1" and "0." As in the decimal system a quantity is represented by the value and the position of a digit. In the binary system, 2 is used as a base for the exponents instead of 10. Therefore, "01" would be 1 and "10" would be 2 (or $1 \times 2^1 + 0 \times 2^0$). Three would be "11" (or $1 \times 2^1 + 1 \times 2^0$), and 4 would be "100" (or $1 \times 2^2 + 0 \times 2^1 + 0 \times 2^0$). What would represent 5, 6, 7, and 8? What is the value of "10101"? This system is used in high-speed electronic computers which, by means of hundreds of vacuum tubes, can perform in a fraction of a second calculations which would take many, many man-hours of tedious effort. In such a machine the number 21 would be recorded as impulse-blank-impulse-blank-impulse (10101).

Numbers as Abstractions

Numbers themselves are abstract symbols which are used to represent other things which do exist. Some persons find reasoning in terms of abstract quantitative symbols very easy, others have to work hard at it, and still others find it impossible. If you were able to comprehend the two preceding paragraphs without too much difficulty, you probably have some facility in mathematics. If you were interested enough to reason out the answers to the questions, you probably will enjoy studying mathematics and engineering science. If, on the other hand, the first question stumped you and you skipped over the remainder, you have just received a small hint that maybe engineering is not the career for you.

Positive and Negative Numbers

The so-called Arabic numerals 1, 2, 3, . . . were actually invented by the Hindus who have made many contributions to mathematics. The Roman numerals I, II, . . . V . . . X . . . are still used widely for certain purposes, but it is difficult to perform such operations as MCMLIV times XIX. The whole numbers 1, 2, 3, etc., are called positive *integers*. Negative numbers were introduced comparatively recently. As has been the case with much of mathematics, the concept of a negative number was devised to solve a problem which could not be solved otherwise ($x + 1 = 0$; find x). An engineering application might be when a pressure of 15 psi is decreased by 20 psi. The result is a pressure of -5 psi, or we may call it 5 psi of vacuum (negative pressure).

Zero

Zero is another relatively recent (around A.D. 500) concept. It is an integer (whole number) just like -1, $+1$, $+2$, etc., but it has some peculiar characteristics. In multiplication, for example, zero times any number is zero. If we recognize 0 as $(1 - 1)$ and let n be any number, then

$$0 \times n = (1 - 1)n = n - n = 0$$

Zero can be handled just like any other integer in addition, subtraction, and multiplication.

Attempting to divide by zero reveals a contradiction. Suppose

$$3/0 = \text{some number } n$$

From our definition of division, then 3 should equal $0 \times n$, but $0 \times n$ is always 0. For this reason dividing by zero is not permitted. One special case where the effect of dividing by zero is desirable will be discussed later under calculus.

Rational and Irrational Numbers

Any positive or negative integer or any number which can be expressed as the quotient of two integers ($\frac{3}{4}$, 0.635, or 5,263/173) is called a *rational* number. In the process of finding roots or finding the lengths of sides of figures such as triangles or polygons, numbers may arise which cannot be expressed as the quotient of two numbers. The square root of 2, for example, lies between $\frac{141}{100}$ and $\frac{142}{100}$ (1.42). It can be approximated more closely by 1.414214, but it can never be expressed exactly in decimal form. It is called an *irrational* number.

Another irrational number is the important constant π, the ratio of the circumference of a circle to its diameter. In rough calculations we sometimes use the rational number $\frac{22}{7}$ as an approximation of π. Mathematicians have calculated, by a rather involved method, a precise value of π which is correct to 27 decimal places; to 10 decimal places, $\pi = 3.1415926536$. For most engineering calculations a value of 3.1416 is sufficiently precise.

Real, Imaginary, and Complex Numbers

The complete set of rational and irrational numbers makes up the *real* number system. In this system various arithmetic operations such as addition, subtraction, multiplication, division (except by zero), raising to powers, and extracting roots can be carried on. One problem which cannot be solved is $x^2 + 4 = 0$. Solving for x^2 and taking the square root, we have $x = \sqrt{-4}$. But neither -2 nor $+2$ will satisfy the equation, since the square of any real number is positive (or zero).

To solve this problem we add to our numbering system the so-called *imaginary* number $j = \sqrt{-1}$ (mathematicians call this i for imaginary but engineers use j to avoid confusion with the symbol i used for electric current intensity). Then

$$j^2 = j \times j = -1 \qquad \text{and} \qquad (j2)^2 = (j^2)(2^2) = (-1)(+4) = -4$$

or

$$\sqrt{-4} = \sqrt{-1} \cdot \sqrt{+4} = (j)(\pm 2) = \pm j2$$

Letting $x = \pm j2$, the equation is satisfied.

A combination of a real number and an imaginary number is called a *complex* number. In working with complex numbers, the real and imaginary parts must always be kept separate. Multiplication of complex numbers is illustrated in the following examples.

$$(3 + j4)(2 + j5) = 6 + j8 + j15 + j^2 20 = 6 - 20 + j23 = -14 + j23$$
$$(3 + j4)(3 - j4) = 9 + j12 - j12 - j^2 16 = 9 + 16 = 25$$

Do you get the idea? You can test yourself on the following problem: One of the cube roots of $+1$ is approximately $(-0.5 + j0.866)$; check this by multiplication. These complex numbers are particularly useful in electrical engineering.

SYMBOLS

$$m = \frac{m_0}{\sqrt{1 - v^2/c^2}} \quad (1) \qquad \Sigma F = 0 \quad (2)$$

What are the meanings behind these cryptic representations? In addition to working with abstract numbers, engineers and scientists make use of symbols representing physical quantities which may take any of a series of numerical values. These quantities are then called *variables*, and physical principles are expressed as relationships among variables.

Physical Relationships

Equation (1) is another portion of the Einstein theory. It says that when a body is in motion, its mass tends to increase; its high-velocity mass will be greater than its original or rest mass by a factor which depends on the ratio of its velocity to the speed of light. Can you identify the variables which are represented by each symbol? Equation (2) is a shorthand method of stating that when a body is in equilibrium, the summation (Σ) of all the forces (F) must be zero; in other words, positive and negative forces must cancel out, leaving no unbalanced forces.

Symbolic equations of this type express relationships which would require many words of explanation. In addition, when a relationship can be expressed symbolically, all the tools of mathematics can be used in analyzing and applying the principle. When an engineer looks at an equation of this type, he must see it as a statement of physical relationship and not just as a formula into which numbers can be inserted and an answer cranked out.

For example, consider the equation $i = (E_m \sin 2\pi ft)/(R + j2\pi fL)$. The engineer visualizes this as an expression of the fact that the instantaneous electric current i in a circuit is proportional to the instantaneous voltage $E_m \sin 2\pi ft$ and limited by the impedance $R + j2\pi fL$. The voltage has a maximum value E_m and varies with time t trigonometrically (sin). The impedance is a complex quantity made up of two parts, the resistance R and the reactance $2\pi fL$. The reactance is expressed as an imaginary number j and is proportional to frequency f and inductance L. If an ammeter were placed in the circuit to your study lamp, it might read 1.25 amp, but the engineer must realize that 1.25 is just a particular value of a current which bears a definite relationship to several physical variables.

Formulas

Strictly speaking, a formula is a prescribed method for doing something—a calculation, in mathematics. For example, we frequently calculate horsepower of an engine from $\mathrm{Hp} = 2\pi NT/33{,}000$, where N is the speed and T is the torque. On the income-tax blank there is a formula for computing tax: "Take 20 per cent of the first \$2,000 of net income. . . ." The engineering student must realize that equations similar to those of the preceding section are more than mere formulas; they are relationships among variables, symbolic representations of physical principles.

Rational and Empirical Relations

Some formulas are exact because of their theoretical nature or by definition. The area of a triangle is exactly one-half the base times the altitude. One foot is exactly equal to twelve inches. In general, however, physical relationships hold only within certain limits. If the relationship among the variables is understood and can be "reasoned out," the relationship is said to be *rational*. For example, if we consider the energy transformation when a body falls in a vacuum from a height h under the acceleration of gravity g, an expression can be derived for the velocity, $V = \sqrt{2gh}$. This relationship can be applied to free fall in air if the limitations are kept in mind. The error is small in calculating the velocity of a massive body falling a short distance because air resistance is negligible. The equation would be useless, however, in the case of a falling feather or parachutist.

If the relationship is based on experiment or observation alone without recourse to science or theory, it is said to be empirical. In 1775 the French hydraulic engineer Chézy established experimentally that the velocity of flow of water in an open channel follows the equation $V = C\sqrt{RS}$, where R is the hydraulic radius, S is the slope of the channel bed, and C is the so-called Chézy coefficient which depends on the characteristics of the channel. While great progress has been made in fluid mechanics in the last 200 years, we have not been able to develop a completely rational replacement for this empirical equation.

Analysis and Synthesis

Recognizing the physical relations represented by a symbolic equation is a form of *analysis*, resolving something into its elements. Conversely, the engineer must be able to *synthesize*, combine elements into a whole. (This is another form of "design.") Suppose that experiment reveals that the force between two charged particles is proportional to the charges on the particles and inversely proportional to the distance between them. How can this be expressed mathematically?

One way to express the first observation is to write

$$F = K'Q_1Q_2$$

where F is the force, Q_1 and Q_2 are the charges, and K' is a constant of proportionality.

The second observation can be expressed as

$$F = \frac{K''}{d^2}$$

where d is the distance and K'' is a different constant of proportionality.

The two ideas can be combined in a single relation

$$F = K\,\frac{Q_1Q_2}{d^2}$$

where K is another constant of proportionality. In algebraic symbols this equation says that "the force is directly proportional to the product of the charges and inversely proportional to the distance." This relation was first expressed by the French engineer Coulomb in 1780.

TOOLS

Coulomb's law was derived in the preceding paragraph using *algebra*, a method of calculating by letters which represent numbers. The basic mathematical tools used by engineers include algebra, geometry, trigonometry, analytical geometry, and calculus.

Algebra

The most useful branch of algebra is concerned with equations involving unknown quantities whose values are to be determined. A typical problem is as follows:

> A reservoir is being filled by two pumps. Pump A can fill the reservoir in 6 hr, and pump B can fill it in 3 hr. How long will it take with the two pumping together?

The first step in the solution consists of representing the unknown quantities by symbols or letters and expressing the given relations in terms of those variables.

> Let t be the time required in hours and R be the total capacity of the reservoir.
> Then $R/6$ is the amount pumped per hour by pump A and $R/3$ is the amount pumped per hour by pump B.

The physical fact that the reservoir is filled in t hr is expressed by the equation

$$\frac{R}{6}t + \frac{R}{3}t = R$$

The second step in the solution consists of using the manipulative tools of algebra. ("Both sides of an equation may be multiplied by the same number without affecting the equality.")

Multiply by 6: $Rt + 2Rt = 6R$
Multiply by $1/R$: $t + 2t = 6$
or $3t = 6$
Multiply by ⅓: $t = 2$ hr
Checking, $\frac{R}{6}2 + \frac{R}{3}2 = \frac{R}{3} + \frac{2R}{3} = R$

This problem is typical of many encountered in engineering study. It requires the ability to think in abstract terms, translate physical relationships into mathematical terms, reason logically, and perform mathematical manipulations without mistake. This ability is more closely related to success in engineering school than any other single characteristic. Do you have this ability?

Trigonometry

Elementary trigonometry is concerned with triangles and the measurements of sides, areas, and angles. An angle is generated when a line is rotated about a point. The size of an angle is measured in degrees (°), with a full circle being 360°. When the line is perpendicular to its original position, it has made a quarter turn, or it has turned through an angle of 90°. The use of 360° is based on the sexagesimal (60) system of the early Babylonians. Each degree is divided into 60 minutes, and each minute into 60 seconds.

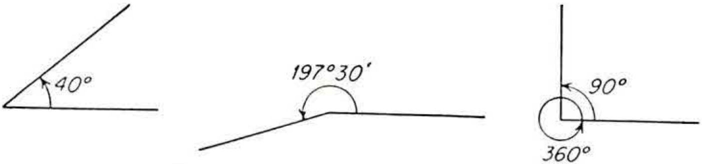


FIG. 14-1. Angular measurement.

Suppose you had the problem of determining the height of a tall redwood tree. One method would be move away, say, 200 ft from the base of the tree and measure the angle from the horizontal up to the treetop, say 50°. Drawing a similar triangle on paper with a 20-in. base and a 50° angle, the opposite side representing the tree would measure approximately 24 in. By proportion, you could estimate the height as 240 ft.

Instead of drawing a new triangle for each problem, you might realize that the ratios of the sides in a triangle depend only on the angles. In a *right* triangle (having one 90° angle), the side opposite a 50° angle will always be approximately $^{240}/_{200}$ times the adjacent side. This ratio of opposite side to adjacent side is used so frequently that it is given a name —the *tangent*. More precisely the tangent of a 50° angle is 1.1918. In general, tangent $A = a/b$. Similarly the other ratios are named: a/c is called the *sine* of angle A, and b/c is called the *cosine* of angle A. These ratios are called trigonometric *functions*, and precise values have been calculated for all angles and fractions of angles. These are in tables available for use in problems in astronomy, physics, and engineering.

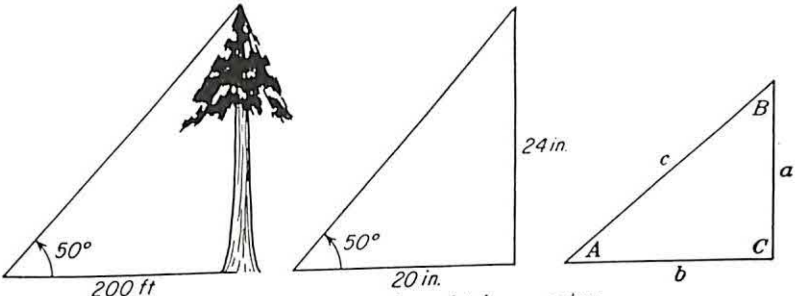


FIG. 14-2. Application of trigonometry.

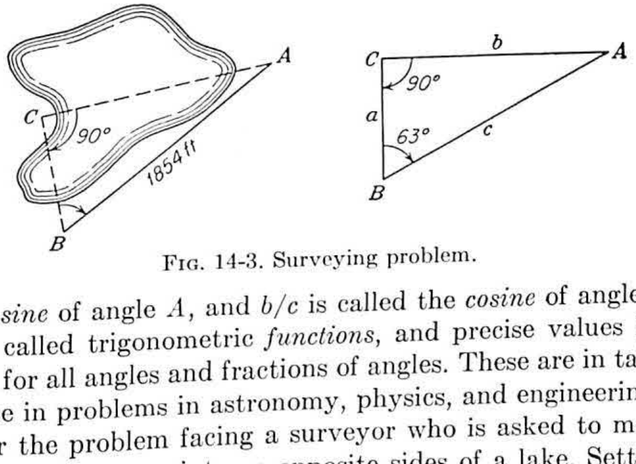


FIG. 14-3. Surveying problem.

Consider the problem facing a surveyor who is asked to measure the distance between two points on opposite sides of a lake. Setting up his engineer's transit at point C, he sights on point A and turns a 90° angle. His assistant places a stake at a convenient point B on the new line of sight. The surveyor then sets up his transit at point B and sights on C. Turning the telescope to A enables him to read the angle at B as $63°0'$. The distance AB is measured as 1,854 ft. By definition

$$\text{sine angle } B = \frac{\text{side } b}{\text{side } c}$$

or

$$b = c \text{ sine } B$$

From the tables on page 356, the sine of 63° is found to be 0.891; therefore,

$$b = 1{,}854 \times 0.891 = 1{,}652 \text{ ft}$$

Geometry and Analytical Geometry

Geometry means, literally, "earth measurement," and its origin is usually ascribed to Egyptians. We can imagine its application to problems of relocating boundary lines after the periodic Nile River floods. Geometry is concerned with the properties of space and involves points, lines, and planes. Euclid (about 300 B.C.) is credited with the development of elementary geometry in its present form. As you recall from high school courses, the methods of geometry are sometimes laborious because they depend upon graphical representation.

Analytical geometry is a method of representing points, curves, and surfaces by means of equations. This makes it possible to apply the powerful tools of algebra to geometry problems. The location of any point in a room can be specified by three numbers representing the distances from, say, the west wall, the south wall, and the floor. For locating a point on a plane we select an *origin* (*O*) and two perpendicular *axes* (x and y) as in Fig. 14-4. The point (1, 3) is 1 unit along the x axis and 3 units along the y axis. Any point on the plane is specified by a pair of numbers (*coordinates*); the x coordinate is always given first. From the origin, positive values are laid off to the right and upward and negative values to the left and downward.

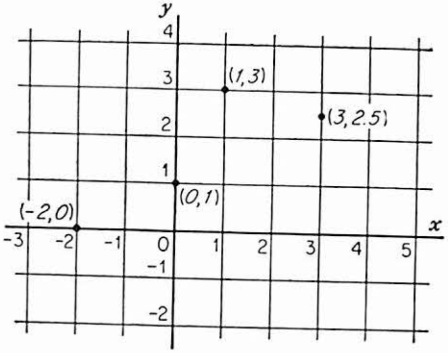


FIG. 14-4. A coordinate system.

How can an equation represent a line? Consider the equation

$$y = \tfrac{1}{2}x + 1$$

For each value of x there is a corresponding value of y. If $x = -2$, $y = 0$; if $x = 0$, $y = 1$; if $x = 3$, $y = 2.5$. But each pair of values represents a point on the plane. The points $(-2, 0)$, $(0, 1)$, and $(3, 2.5)$ have been plotted in Fig. 14-3. Reproduce this drawing on notebook paper. What values of y correspond to $x = -1, 1, 2$, and 4? Plot these points on your coordinate system. It is seen that all points whose coordinates satisfy the given equation lie on a straight line. Draw in this line. The line is called the *locus* of the equation and is said to represent the equation *graphically;* the equation represents the line *analytically*.

Since a geometrical figure, the line, can be represented by an algebraic equation, the methods of algebra can be applied to geometry problems. For example, find the point of intersection of the line $y = \frac{1}{2}x + 1$ and the line $y = 4 - x$. Since the point of intersection must lie on both curves, its x and y coordinates must satisfy both equations. To find values of x and y which satisfy both equations, the two equations are solved simultaneously. At the point of intersection, both lines must have the same y value or

$$\begin{aligned}
&& y &= y \\
&\text{Therefore,} & \tfrac{1}{2}x + 1 &= 4 - x \\
&\text{Multiply by 2,} & x + 2 &= 8 - 2x \\
&\text{Add } 2x \text{ to each side} & 3x + 2 &= 8 \\
&\text{Subtract 2 from each side} & 3x &= 6 \\
&\text{Divide by 3} & x &= 2 \\
&\text{and} & y &= \tfrac{1}{2}x + 1 = \tfrac{1}{2}(2) + 1 = 2
\end{aligned}$$

Therefore the point of intersection is (2, 2). Check this by plotting the line $y = 4 - x$.

Another great advantage of analytical geometry is that perfectly general problems can be solved. Suppose you were asked to find the point of intersection of $y = ax + b$ and $y = cx + d$. The general solution can be obtained algebraically just as in the specific case; the answer is the point $(d - b)/(a - c)$, $(ad - cb)/(a - c)$. Could you ever find it by graphical means? The great advantage of a general solution is that once it has been worked out, it can be used for any particular problem. In the preceding problem if $y = ax + b$ represents $y = \frac{1}{2}x + 1$, then $a = \frac{1}{2}$ and $b = 1$. What are the values of c and d? Use the general solution to check the point of intersection.

Calculus

One of Sir Isaac Newton's great contributions to science was his "method of fluxions" which he developed in order to solve complex motion problems. Newton and Baron Gottfried von Leibnitz, working independently, both developed systems of notation which have been modified into what we now call calculus. *Differential* calculus is used to determine the relation between small changes or *differences* in quantities when the relation between the quantities, or variables, themselves is known. *Integral* calculus is used to solve the inverse problem, that is, to determine the relation between variables when the relation between their differences is known.

Suppose that experiments are being conducted on a rocket. The distance traveled at the end of each second is measured as follows:

Distance D, ft.	0	25	100	400	900	1,600
Time T, sec.	0	0.5	1	2	3	4

For each value of time there is a value of distance, so distance D is said to be a function of time T. On the basis of experience we identify the function as

$$D = 100T^2$$

(Check this by substituting some pairs of values.) How can we find the *velocity* which is equal to distance divided by time and measured in feet per second? During the first second the rocket traveled 100 ft so its velocity was 100 ft per sec, but during the last second it traveled 700 ft. Apparently the velocity is changing, and it also is a function of time. Our problem is to find that function. Calculus is particularly useful in dealing with changing values, whereas algebra is used for finding particular values.

We find the *average* velocity over the full 4 sec as

$$V_{\text{ave}} = 1{,}600 \text{ ft}/4 \text{ sec} = 400 \text{ ft/sec}$$

A better picture of the velocity changes would be obtained from the distance traveled each second. Still better approximations could be obtained if measurements were made for each 0.1 or 0.01 sec, but these would still be averages because the velocity is changing continuously. Apparently to get a true instantaneous velocity V we must carry this process to the limit; we must let the time interval go right up to *zero*. Dividing by zero time (to get velocity) is prohibited, but in this case, as the denominator, time, approaches zero, the numerator, distance, will approach zero also and $0/0$ can be handled by calculus methods. Given

$$D = 100T^2$$

Consider a small difference in time t and a corresponding difference in distance d. Then

$$D + d = 100(T + t)^2 = 100T^2 + 200Tt + 100t^2$$

Calculate the *change* in distance by subtracting $D = 100T^2$, leaving

$$d = 200Tt + 100t^2$$

The average velocity over the short time t will be

$$V_{\text{ave}} = \frac{d}{t} = 200T + 100t$$

Now, and this is the important concept, let the time t get smaller and smaller until it disappears. On the right-hand side of the equation only $200T$ will be left. By definition, the left-hand side of the equation is instantaneous velocity. Therefore

$$V_{\text{inst}} = 200T$$

In other words, when $T = 1$ sec, the velocity is 200 ft per sec; when $T = 3.3$ sec, $V = 660$ ft per sec.

This is a typical application of differential calculus. The corresponding problem in integral calculus would be: Given a velocity as a function of time, find the distance traveled as a function of time. These are simple problems which could be solved without calculus, but there are many problems where calculus is the only practical method, and a knowledge of calculus is a valuable tool for the engineer.

SUMMARY

Engineering is primarily a mental activity, and ability to think in terms of symbols and abstractions is important. While the work of the engineer varies a great deal from function to function, there is, in all engineering, emphasis on reasoning in quantitative terms. Because these same characteristics are required for success in mathematics, ability in mathematics is a good indication of probable success in engineering studies. Mathematics is a valuable tool for the engineer. Like any other tool it should be forged carefully, sharpened to a keen edge, and used in such a way that it retains its effectiveness.

ASSIGNMENTS

14-1. *a.* Write out the binary system numbers corresponding to the decimal system numbers from 1 to 32.

b. Find the decimal system equivalents of the following binary numbers: 000111, 011001, 101010, 111001.

14-2. Make up a numbering system with 16 as a base using Greek letters to represent the other necessary digits as follows: 10, ι (iota); 11, α (alpha); 12, β (beta); 13, γ (gamma); 14, δ (delta); and 15, ϵ (epsilon).

a. Express, in the new system, the following decimal numbers: 16, 256, 64, 67, 59, 0.5, 0.75.

b. Find the decimal value of "2β," "$\alpha\epsilon$," "$0.\delta$," "$0.\gamma\iota$."

14-3. Solve the following equations and check the results by substitution:

a. $2t^2 + 2t - 6 = t^2 + 2t - 15$ Answer: ($t = \pm j3$)

b. $x^2 + 4x + 13 = 0$

14-4. Over a certain range of speeds the horsepower required to propel a ship is proportional to the cube of the speed.

a. Express this fact algebraically using suitable symbols.

b. If 400 hp is required to drive a particular ship at a speed of 10 mph, write an equation expressing the relationship between power and speed for this ship.

c. Calculate the power required at a speed of 15 mph. (Answer: 1,350 hp)

14-5. It took a number of draftsmen as many days to turn out a set of drawings as there were draftsmen, but if five more draftsmen had been employed, the work would have been done four days sooner. How many draftsmen were employed?

14-6. How many pounds of pure tin should be added to 10 lb of a bearing metal containing 50 per cent tin and 50 per cent copper to yield a mixture containing 60 per cent tin? (Answer: 2.5 lb) Hint: Let x = number of pounds of tin to be added. Write expressions for the total pounds of tin and total pounds of mixture. Express the fact that the resultant proportion must be 60 per cent and solve.

14-7. Given a right triangle with sides $a = 12$ ft and $b = 16$ ft; find side c and angles A and B to the nearest degree. (Answer: $c = 20$ ft, $A = 37°$, $B = 53°$)

14-8. Given a right triangle with sides $a = 618$ ft and $c = 2000$ ft; find side b and angles A and B.

14-9. Given a right triangle with angle $B = 58°$ and side $c = 200$ ft; find sides a and b.

14-10. A new throughway is to traverse a mountain range at a constant grade of 5 per cent (5-ft rise in each 100 ft of horizontal distance). Approximately what is the angle of inclination of the roadbed?

14-11. Plot the locus of the equation $y = x^2 - 2$.

a. Select several values of x (both + and −), and find the corresponding values of y.

b. Lay off an origin and axes on coordinate paper.

c. Plot the points, and draw a smooth curve through them.

14-12. Repeat 14-11 for the equation $x^2 - 4x + y^2 - 6y - 12 = 0$.

14-13. *a*. Find the point of intersection of the lines $2y = x - 6$ and $y = -2x + 2$ by simultaneous solution.

b. Plot a few points on each line on coordinate paper and determine the point of intersection graphically.

14-14. *a*. Solve the equations $2y = x - 4$ and $y = 4 + \frac{1}{2}x$ simultaneously.

b. What is the graphical interpretation of your result in Part *a*?

c. Demonstrate the correctness of your reasoning in Part *b* by plotting the lines representing the two equations.

15

THE ENGINEERING METHOD OF PROBLEM SOLUTION

Assume that you are a construction engineer building a dam in the Santa Cruz Mountains. One operation involves hoisting a 6-yd bucket of concrete to a height of 120 ft in 2 min. The time for unloading, descent, and loading is estimated to be 3 min. Available to operate the hoist are the following motors: 10, 20, 50, and 100 hp. The construction crew works two shifts. What motor do you recommend, and what will be the monthly power bill?

One activity common to all engineering work is problem solution. The problems may involve quantitative or qualitative factors; they may be physical or personal; they may require abstract mathematical and scientific concepts or merely common sense. The preceding problem is typical of some of the simpler problems faced by engineers in their daily work. The solution requires the same approach as many more difficult problems. The ability to attack and solve problems is one of the most valuable technical skills, and much of engineering training is directed toward developing this ability.

The discussion of the engineering fields emphasized the *results* of engineering efforts. The section on engineering functions described *what* engineers do. This chapter will attempt to explain *how* they go about it. In subsequent chapters you will be given an opportunity to try your hand at solving simple engineering problems. Obviously problems to be solved by beginning students must be of limited scope. For the next 4 years you will be gaining a background of factual information, a knowledge of engineering principles, and skill in applying them to more complex problems. After graduation you will begin to gather the experience which will develop the judgment needed in the solution of real problems. The purpose of this chapter is to describe the general engineering method which can be applied to problems in many fields. It is felt that with this background you will be in a better position to benefit from your technical studies.

ILLUSTRATIVE PROBLEMS

Let us consider some very elementary problems and try to discover the basic steps in their solution.

PROBLEM A: What is the highest speed reached by the Southern Pacific Daylight on the run between San Francisco and San Jose?

Well (you might say to yourself), there are at least three approaches to this problem: (1) I could call up the division office of the Southern Pacific and ask; (2) I could take the trip and make my own observations with a stop-watch and the track mileage markers; (3) I could calculate an approximate speed if I knew the values of distance and time. The most direct method would be to ask someone who knows. Upon calling the Southern Pacific I find that the trainmaster is in a meeting and cannot be reached. The time and expense of the second approach isn't justified under the circumstances. The third method is simple, and the approximate answer would be satisfactory.

To calculate speed I need distance and time. I know it is 47 miles by highway from San Jose to San Francisco. The schedule shows that the Daylight leaves San Francisco at 8:15 A.M. and leaves San Jose at 9:12 A.M. I visualize the train slowly pulling out of the station, threading its way through the yards, accelerating to a maximum speed on the level run, slowing down on the outskirts of San Jose, and finally coming to a stop. If I assumed that the distance was the same by rail and highway, that the train averaged 30 mph for the first and last 10-min periods, made a 5-min stop at San Jose, and traveled at a constant speed the rest of the trip, the problem could be solved. The new statement would be: If a train goes 47 miles in 57 min with 10 min each for acceleration and deceleration (at an average speed of 30 mph) and 5 min for a stop, find the average speed for the remainder of the trip.

During the acceleration and deceleration periods the train would travel

$$\frac{10 \text{ min}}{60 \text{ min/hr}} \times 30 \text{ mph} = 5 \text{ miles}$$

since time × rate = distance. The remaining distance would be

$$47 - 5 - 5 = 37 \text{ miles}$$

The remaining time would be

$$57 - 10 - 10 - 5 = 32 \text{ min}$$

The average speed over this interval would be

$$\frac{37 \text{ mi} \times 60 \text{ min/hr}}{32 \text{ min}} = 69.5 \text{ mph}$$

This seems reasonable because traveling by automobile with a top speed of 55 mph requires about 1 hr and 20 min for the same trip. Just then the trainmaster's secretary calls back to say that she recalls hearing that the maximum authorized speed on that run is 75 mph.

Going back to the original problem, it appears that of the assumptions made, only the acceleration times would be far off. Of course the answer is only approximate, and a proper answer, considering the limits of accuracy of the data, would be 70 to 75 mph.

The above solution has been divided into five separate steps as indicated by the five paragraphs. Look back over the solution, and see if you can discover what distinct process was performed in each paragraph.

Now let us consider another slightly more involved problem. As you read the solution, try to analyze the work into distinct steps.

PROBLEM B: You are the production engineer of a small manufacturing plant. One morning the purchasing agent brings the news that the company which supplied a certain small shaft for $1,100 per thousand has had a fire and is out of business. The only other supplier wants $1,600 per thousand. What is to be done?

Well, you say to yourself after the purchasing agent leaves, we might make them ourselves or maybe it's cheaper to buy them outside. We do have a turret lathe that could do the job, and our shop is not unusually busy. I wonder what it would cost to make the shafts in our own shop taking into account labor, materials, and overhead. (This first step is an analysis of the over-all situation; it involves identifying the important factors and deciding on the general method of approach.)

I need to know how long it would take for our men to make the shafts. I ask the turret-lathe operator to set up for production (this takes 2 hr), and he makes 5 shafts in times of 6, 5, 4, 3, and 3 min, respectively. I tell him to finish out the day on the shafts in order to take advantage of the setup time already invested. The industrial engineer tells me that he figures shop time on the turret lathe at $10 per hr including overhead. The shafts are 6 in. long, and the purchasing agent estimates the steel bar stock will cost about 60 cents per ft. If I assume 3 min per shaft, specify costs for shop time and material, and neglect all other charges, I have a solvable problem: What is the cost per unit of making shafts on a 3-min schedule with shop time at $10 per hr and raw materials at 30 cents per shaft? (The purpose of the second step is to reduce the original vague problem to a question which can be answered.)

At 3 min per shaft, the output will be

$$\frac{60 \text{ min/hr}}{3 \text{ min/shaft}} = 20 \text{ shafts per hr}$$

The labor cost will be

$$\frac{\$10/\text{hr}}{20 \text{ shafts/hr}} = 50 \text{ cents per shaft}$$

The total cost will be

$$30 \text{ cents material} + 50 \text{ cents labor} = 80 \text{ cents per shaft}$$

(The simplified question is then answered.)

For 1,000 shafts, this would be \$800. This agrees with the previous price of \$1,100 per thousand, allowing for profit and costs of transportation and handling. (The answer to the simplified question is checked by an independent method.)

In looking over my solution, I feel that the assumptions are quite conservative. The machinist got down to 3 min quickly, indicating that the time allowance is liberal. The \$10-per-hr figure for the turret lathe has been developed after careful study. The \$800 margin between our cost and the outside quotation will cover any extra management charges and still yield a good saving. I recommend that we make the shafts in our own shop. (The final step is application of the result for the simplified problem to the original situation.)

THE ENGINEERING METHOD

While engineering problems vary greatly in scope and complexity, the same general approach is usually employed. First comes an analysis of the over-all situation and a preliminary decision on a plan of attack. In line with this plan, the usually broad and vague problem is then reduced to a more or less straightforward question which can be clearly stated. The stated question is then answered by direct or indirect means. The results for the stated question are always checked for accuracy. Finally the results for the stated question are interpreted in terms of the original problem. The five steps then are *analysis, statement, solution, check,* and *interpretation.*

Preliminary Analysis of the Over-all Problem

Engineering problems are never in the form of complete, well-defined questions of the type found in textbooks. Usually the problem handed to the engineer is quite vague and lacking in factual data. The electronic development engineer might be asked: How can we obtain stable oscillator operation at 100 mc? The assignment for a structural design engineer might be merely: Design a two-lane bridge across the Guadalupe Creek at Hedding Street. The refinery operating engineer might be asked: What is wrong with the new cracking unit? In each case the first step is a preliminary analysis to determine what type of problem it is, what the important factors are, and what approach or approaches appear promising.

The initial step is determining the *nature* of the answer. Will it be a magnitude as the 70 to 75 mph in Prob. A? Will it be a recommendation as in Prob. B? Will it be merely "yes" or "no," a quality ("corrosion resistant"), or a plan ("build according to the accompanying drawing")? The form of the answer may indicate what type of problem it is—technical, economic, or personal. Until the nature of the answer has been determined, the assignment is not clearly understood.

Another preliminary consideration is: What are the important factors, and which are insignificant? Usually the engineer has available far more information than he can use effectively, and at the same time, he almost always lacks certain knowledge that would be helpful. The availability of data concerning the various factors obviously affects the selection of the method to be employed.

Steinmetz is quoted* as saying: "The most important part of engineering work—and also of other scientific work—is the determination of the method of attacking the problem." In Prob. A, direct, experimental, and analytical approaches were considered; Prob. B was solved using a combination of all three. Once a decision has been made on the approach to be followed—and frequently this is where the engineer makes his major contribution—then work on the problem can proceed.

Statement of the Question

The second step consists of reducing the original problem to one or more specific questions for which adequate data are obtainable and to which answers can be found. The necessary data may not be right at hand; obtaining the information may require a study of records, a search of the technical literature, consultation with an expert, or some original experimental work.

Frequently the original problem must be simplified by making idealizing assumptions. In Prob. A it was recognized that the actual variation of speed throughout the run was unobtainable, and therefore the assumption was made that the train averaged 30 mph during the acceleration period of 10 min. In Prob. B, it was decided that the primary factors in determining cost were material, labor, and overhead, and all other costs were neglected. Each of these assumptions simplified the solution.

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* T. J. Hoover and J. C. L. Fish, "The Engineering Profession," Stanford University Press, Stanford, Calif., 1950. This book provides a thorough discussion of "the engineering method."

Sometimes a complex problem can be broken down into a series of simple questions. In Prob. B the sequence was as follows: How long does it take to make a shaft? What then is the labor and overhead charge per shaft? What is the material cost? What is the total cost per shaft? How does this compare with the quoted price? What do I recommend? The more complex the problem, the greater is the need for considering one aspect at a time.

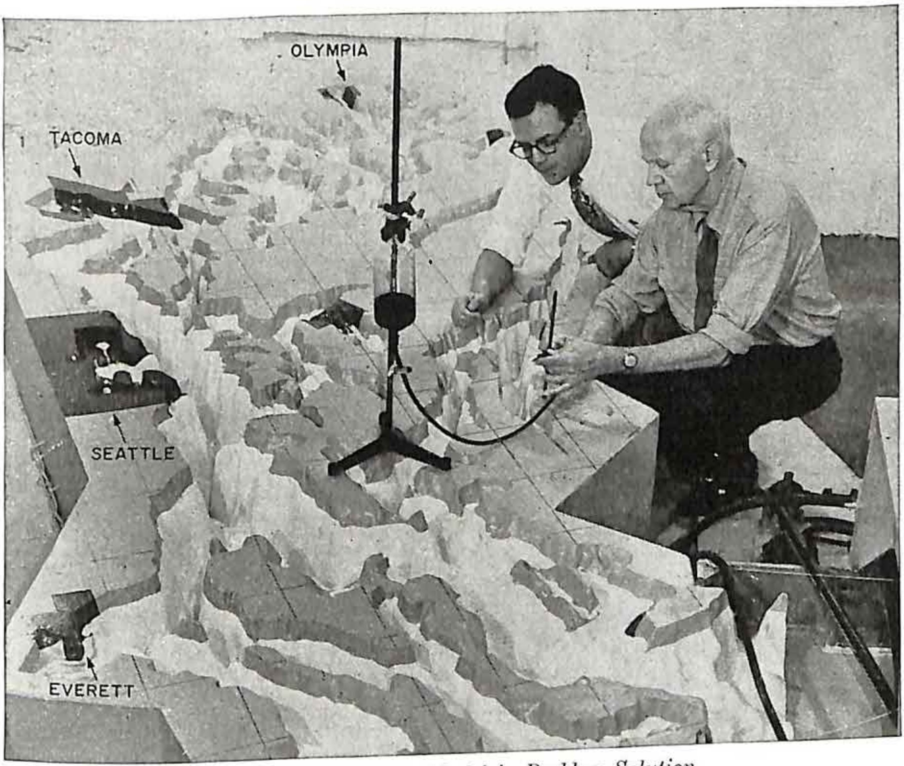
Frequently it will be found that as the solution progresses, additional assumptions must be made. In other cases, later developments indicate that certain assumptions were unnecessary. Since all important engineering problems are being solved for the first time, no two can be handled in exactly the same way. The procedure must be varied to suit the circumstances. In any problem, however, this second step should result in a definite statement of a simplified question or questions for which there appears to be adequate information.

Solution of the Simplified Problem

The solution consists in answering the questions asked in the second step. These answers may be obtained by using direct or indirect means.

Direct Approach. The direct approach is very important in engineering; it includes obtaining the answer by direct observation, from records or other sources, or by asking someone who knows. *Measuring* a desired quantity is one direct approach. Many of the advances in engineering and science have been preceded by improved methods of measurement which revealed new information. In all scientific work it must be remembered that *exact* measurements are not possible; measurements are comparisons which are approximations within certain limits. As these limits are narrowed, the measurements become more *precise*. It should be noted that it is misleading to put qualitative factors on a quantitative scale. For example, it would be deceptive to put "style" on a 0–10 scale and attempt to treat the results mathematically. On the other hand, some qualitative factors have a quantitative basis which may have been overlooked or disregarded. For example, "color" in the garment industry is a qualitative factor, while "color" to the scientist is a matter of wavelength which can be measured with extreme precision.

Estimating is a valuable engineering approach which is used as a quick and inexpensive method to obtain an *approximate* answer, to *predict* results of more precise methods, or to *check* the results of other methods. Estimating means to form, on the basis of judgment, an opinion from imperfect data. For example, the construction engineer estimates the cost of a project by combining calculated costs with those that can only be predicted. Another type of estimating involves imaginary measurement; the height of a building can be estimated by imagining it as so many times as high as a 6-ft man. In these two examples the opinion is the result of applying judgment developed from previous situations.



Use of a Hydraulic Model in Problem Solution

This model of Puget Sound was constructed by the Oceanography Department of the University of Washington (Office of Naval Research sponsorship) for a study of sewage movements through the Sound. The scale is 1:40,000 horizontal and 1:1,152 vertical. The time scale is such that a day is 1.2 minutes in the model and a year is 7.44 hr. The movement of sewage from any existing or proposed outfall can be followed, using the dye applicator shown, until it reaches the ocean. The use of hydraulic models has aided greatly in clarifying many engineering problems too complex for analytical solution. (*From:* The Trend in Engineering at the University of Washington, *January, 1956*.)

Going directly to the result on the basis of experience but without any conscious reasoning is called *intuition*. Intuition is employed many times each day by every one of us. For example, the driver of a passenger car approaching an intersection at the same time as a heavy truck does not employ calculus or slide rule to determine which has the right of way. It is a common experience for a young engineer to present the results of a day's calculations, only to have his experienced superior say: "It just doesn't look right." Intuition based on experience has an important place in engineering. On the other hand, "hunches," unjustified intuition, are not acceptable.

Indirect Approach. Much of engineering work requires indirect reasoning, and this approach is usually emphasized in engineering schools. Many problems can be solved by a combination of *analysis* and *synthesis.*

Analysis consists in breaking a thing down into its elemental parts. A conscious analysis is usually the first step in understanding a problem; it involves identifying the factors and determining their relationships to the problem and to one another. Referring again to Prob. B, step 3, the total cost was analyzed into material plus labor charges. The factors affecting labor cost were recognized to be time per shaft and charge per unit of time. What analytical processes took place in Prob. A?

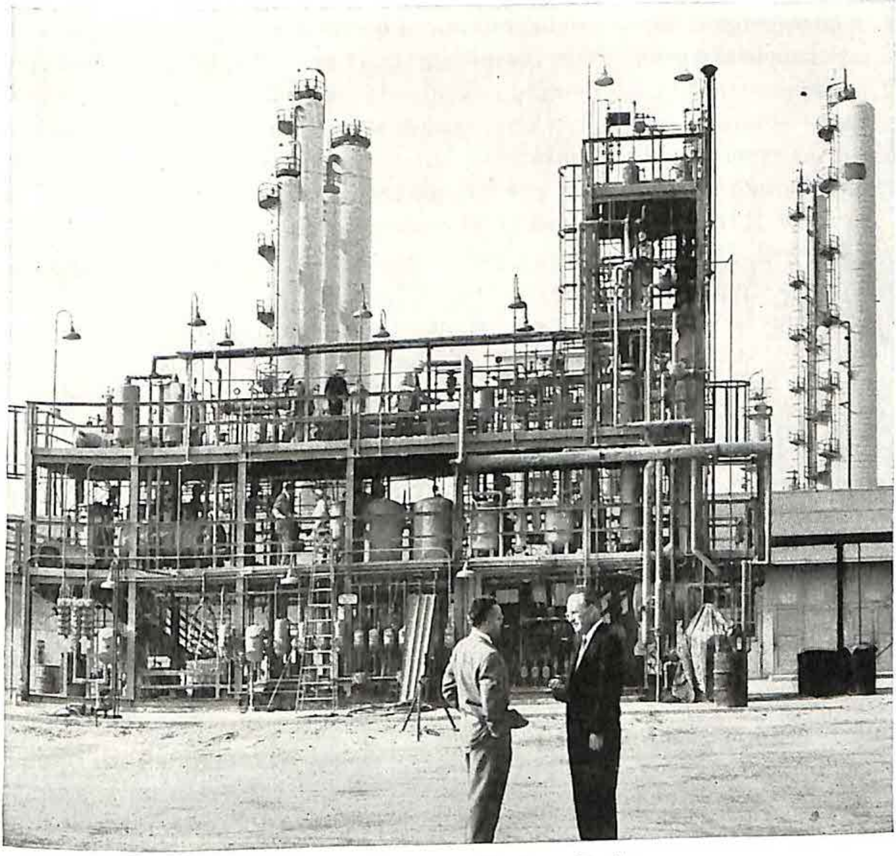
Analysis is carried to the point where the elements can be evaluated. Frequently this evaluation is performed by means of *deductive* reasoning. Deduction is reasoning from the general to the specific, applying the general law to the specific case. In Prob. A, the desired quantity, speed, was identified as governed by the general law, distance = rate × time. Substitution of specific values of distance and time permitted the calculation of a specific speed.

In contrast, *inductive* reasoning works from the specific to the general, developing the general law from specific observations. Inductive reasoning is the tool of scientists and research engineers in discovering new laws, while deductive reasoning is more frequently used by engineers in applying general principles to specific problems. Much of engineering training is directed toward providing a background of principles and techniques by means of which the factors can be evaluated after they have been correctly identified.

Synthesis refers to the combination of separate elements into a whole. Synthesis is an important part of design whether it is the design of a machine, a process, an operating procedure, a report, or a problem solution. After a problem has been analyzed into its components and the components evaluated, the pieces are put back together and the answer built up. In what ways was synthesis used in Prob. B?

Checking the Answer to the Simplified Problem

There are no answer books in engineering practice; usually the engineer who does the work is the only one who can judge the correctness of his results. Because his recommendations may become the basis for large investments in money, time, or human life, and because his professional reputation rides on each decision, the engineer must learn to check his own work effectively. In an engineering problem the method of solution must be checked as well as the calculations. Manipulative mistakes and numerical blunders can be corrected by careful repetition of individual steps. The best check on a method is solution by independent method.



The Pilot Plant as a Check on Design

This is a semicommercial plant for the application of a new process in the production of phthalic acid which is useful in the manufacture of plastics, paints, and synthetic fibers. The original test-tube production by the newly developed process resulted in $\frac{1}{20}$ oz of phthalic acid. The pilot plant will provide the needed checks before construction of the final model on the scale of the refinery units in the background. (*Stanford Research Institute.*)

Methods of Checking. Any method of solution constitutes a possible check for another method. In most cases the ultimate test is a *practical application;* the other methods are used as quicker or less expensive substitutes for the real thing or as preliminary steps prior to the actual construction or operation. An *experimental* solution or check may be obtained in a laboratory by means of a test carefully contrived to yield the desired results. Aircraft-design problems are usually checked experimentally in wind tunnels. In some situations the accuracy of the experimental check can be obtained at less expense by using *models* and extrapolating the data to the full-scale unit. For example, a 4-ft scale model may be used to represent an aircraft of 40-ft wingspread. The *analytical* method depends on a knowledge of fundamental principles derived from previous practice or experimental work and has the advantage of great flexibility in the type of problem attacked. *Estimating* has already been discussed as a method of quick solution, and it has obvious advantages in checking. *Intuition* based on experience has limitations, but the advantage in speed and the generally high dependability justify its frequent use in engineering.

In Prob. B the resultant cost of 80 cents per shaft was checked by comparison with the previous price per thousand on the basis of experience. What two checks were made in Prob. A?

The Time for Checking. Checks should be applied throughout the solution rather than being reserved until the end. Frequent checks increase efficiency by avoiding the waste of time caused by mistakes made in the early stages. Frequently a check solution by estimating or intuition should be made before beginning the more detailed solution. This procedure is especially recommended for engineering students. After the preliminary analysis when the nature of the answer has become clear, make a guess as to the result. This intuitive solution will provide a more reliable check if made ahead of time than if you wait until the analytical results are available to influence your thinking. In any solution, you must guard against being so prejudiced in favor of your own work that you slight the checking process.

Interpretation of the Result

Having solved a simplified problem and checked the results, you must now go back and interpret the results in terms of the original problem. If assumptions were made in order to simplify the solution, their effect should now be considered. If certain factors were neglected, they should now be taken into account either by modifying the result or indicating the precision of the answer. In many cases the problem actually solved was for an idealized situation, and the result must be modified to fit the practical case.

The form of the answer may not agree with the original assignment. Problem B yielded a result in dollars, while the original question called for a recommendation. Sometimes the result will be in a general form to be applied to a specific case. Other times the result will be specific but will have general implications which should be pointed out.

In any case the answer must be reported back to the person making the assignment. This presentation may be short or long, formal or informal, oral or written, one page or several volumes in length. The form of the interpretation must be governed by the requirements of the reader and the intended use of the report. Your instructor will be interested in your method and reasoning; a client will be interested in an answer in dollars and cents; another engineer will wish to know your assumptions and where you used your own judgment. In many situations, you may spend more time on the interpretation than on all the rest of the solution.

APPLICATION OF THE METHOD

Let us now go back to the original problem and solve it by the suggested approach.

PROBLEM: Assume that you are a construction engineer building a dam in the Santa Cruz Mountains. One operation involves hoisting a 6-yd bucket of concrete to a height of 120 ft in 2 min. The time for unloading, descent, and loading is estimated to be 3 min. Available to operate the hoist are the following motors: 10, 20, 50, and 100 hp. The construction crew works two shifts. What motor do you recommend and what will be the monthly power bill?

1. Preliminary Analysis. The selection of a motor will depend directly on the horsepower required to do the job. Other motor characteristics such as speed and operating voltage can be taken care of by gears and transformers, respectively. The power bill is really a charge for energy, and energy is dependent on the total work done.

2. Statement. I know that 1 hp = 33,000 ft-lb per min by definition. Concrete weighs about 150 lb per cu ft. The rate schedule indicates a charge of 1 cent per kwhr for electrical energy. One hp = 0.746 kw by definition. The 100-hp motor has a guaranteed full-load efficiency of 84 per cent. A certain 20-hp motor we checked recently had an efficiency of 78 per cent. The last concrete bucket we built weighed about $1\frac{1}{2}$ tons. From these facts and the given information, I make the following simplifying assumptions:

Assume one round trip each 5 min or 12 trips per hour.

Assume power consumed only during hoisting (2 min per trip).

Assume motor 80 per cent efficient.

Neglect losses in the hoist mechanism.

Assume bucket and all gear weigh 4,000 lb.

Assume 16 hr per day for 25 days per month or 400 hr per month.

On the basis of these assumptions I formulate a new two-part problem:

a. Find the horsepower required to raise 6 yd of concrete plus 4,000 lb a distance of 120 ft in 2 min.

b. Find the cost of electrical energy for a motor at 80 per cent efficiency to make 12 × 400 trips per month.

3. Solution. *a.* Power* is work (W) per unit of time (T), or $P = W/T$. Mechanical work* is force (F) × distance (D) or $W = F \times D$.

$$\text{Power in hp} = \frac{\text{force in lb} \times \text{distance in ft}}{\text{time in min} \times 33{,}000}$$

The force here is the force required to lift the load against gravity and equals the weight of the bucket, gear, and concrete. The concrete weighs 6 yd × 27 cu ft per yd × 150 lb per cu ft. Therefore,

$$F = 6 \times 27 \times 150 + 4000 = 24{,}300 + 4{,}000 = 28{,}300 \text{ lb}$$

$$P = \frac{F \times D}{T \times 33{,}000} = \frac{28{,}300 \times 120}{2 \times 33{,}000} = 51.5 \text{ hp}$$

b. The charge in dollars per month = 1 cent per kwhr × kwhr per month. Efficiency* = output/input, or input power = output/efficiency. Therefore,

$$\text{Input in kw} = \frac{\text{output in hp}}{\text{efficiency}} \times 0.746 \text{ kw/hp}$$

$$= \frac{51.5 \times 0.746}{0.80} = 48 \text{ kw}$$

The motor consumes power for only 2 out of 5 min.

$$\text{Monthly charge} = \$0.01 \times 48 \text{ kw} \times 2/5 \times 400 \text{ hr/mo} = \$76.80$$

4. Check. *a.* As an approximate check on the magnitude of the result, I recall that on a previous job we used a 20-hp motor but we were using a 3-yd bucket.

To check my numerical calculations, I might find how long it would take a 50-hp motor to raise a load of 28,300 lb a distance of 120 ft.

$$T = \frac{W}{P} = \frac{F \times D}{P} = \frac{28{,}300 \times 120}{50 \times 33{,}000} = 2.06 \text{ min}$$

which *checks*. (Note that this includes no check on the assumptions.)

b. Similarly I can check the cost calculations by setting up a different equation:

$$C = \frac{\text{total work done}}{\text{work/kwh}} \times \text{dollars/kwh}$$

$$\text{Total } W = 28{,}300 \text{ lb} \times 120 \text{ ft} \times 12 \text{ trips/hr} \times 400 \text{ hr/mo}$$

Converting work output into kilowatt-hours input requires dividing by efficiency, dividing by 60 × 33,000 to convert into horsepower-hours, and multiplying by 0.746 to obtain kilowatt-hours. Therefore

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* These terms are discussed in detail in Chap. 16.

$$C = \frac{28{,}300 \times 120 \times 12 \times 400}{0.80 \times 60 \times 33{,}000} \times 0.746 \times \$0.01 = \$77$$

(Again note that this is only a check on arithmetic.)

5. Interpretation. Looking over the assumptions, I conclude that the actual power required will be greater than 51.5 hp because of the losses in the hoisting mechanism. On the other hand, the 3-min cooling period will prevent any overheating of the 50-hp motor. The 100-hp motor would be expensive to operate because the efficiency is a maximum near full load. Of the motors available, *I recommend the 50-hp motor.*

In regard to operating cost, the losses while idling and the losses in the hoist will tend to increase the figure obtained previously. However, there will be loss in time of operation for various reasons, which will partially offset the additional cost. I conclude that *the monthly power bill will be around* $80 *to* $85.

SUMMARY

One of the characteristic activities of engineers in all functions is the solution of problems. A logical, step-by-step approach is recommended. The major steps are

1. *Preliminary analysis* of the over-all problem
2. *Statement* of the question in simplified form
3. *Solution* of the simplified problem
4. *Check* on the answer to the simplified problem
5. *Interpretation* of the result in terms of the original problem

In college engineering courses, the major emphasis is on step 3 with some training in the background required for steps 2 and 4. Experience on the job will help in steps 1 and 5 particularly. As you work simplified problems in specialized courses, bear in mind that in practice, problems do not come wrapped up in such neat packages.

ASSIGNMENTS

Solve these problems using the approach outlined in this chapter. Label clearly the five steps in the solution. State all assumptions made; your instructor will assist you in making the simplifying assumptions.

A knowledge of high school physics is adequate technical background for the problems, although you may wish to study the page references provided. Some useful conversion factors and typical engineering data are given in Appendix A. Note that there is no one correct answer for any of the problems; the method of approach is the important factor.

15-1. A contractor is estimating a concrete job. A slab is to be poured in the shape of a rectangle 30 by 45 ft. What price should he quote? (Note: his last job was a drive-way 9 ft wide and 50 ft long. On that job his direct costs were putting in forms, $24; transit-mix concrete, $55; placing and finishing, $40.)

15-2. For some time the Zilch Paper Co. has been providing cars and traveling expenses for its salesmen. In 1955 they purchased new Chevrolets for $2,250 and a year later received $1,750 in trade on 1956 models. The management has decided to simplify its accounting by having the salesmen buy and maintain their own cars and paying them a flat rate per mile. What rate in cents per mile would be fair?

The records of the Zilch Paper Co. for 1955–1956 show the following:

Average mileage per car	19,258 miles
Insurance per car	$165
Average maintenance cost per car	$102.50
Average hotel bill per night	$5.80
Color of car preferred by salesmen	Green

15-3. A gravel conveyor is being designed to raise 100 tons per hr through a vertical distance of 30 ft. What horsepower rating (see page 276) do you recommend for the driving motor?

15-4. In a manufacturing plant, a 220-volt, 1,200-rpm electric motor drives a centrifugal pump which circulates cooling water. The pump operates during working hours and requires an input of 20 hp. What will be the monthly power bill for this electric motor (see page 307)?

15-5. A 10-hp diesel engine is used to drive a pump operating 8 hr per day. If fuel-oil delivery is to be once a month, how large a storage tank should be provided (see page 293)?

PART THREE

THE ENGINEERING SCIENCES

16

PREVIEW OF ENGINEERING MATERIALS AND MECHANICS

Out in the shop there is a heavy piece of new equipment which must be rigged so that it can be swung horizontally through a 6-ft radius; you have been asked to design a suitable crane. This is a typical problem in the field of mechanics of materials. How would you go about solving it?

Since the purpose of the crane is to support a heavy load, the first question might be: What is the effect of the load on the crane? Another way of stating the same question is: What forces must be resisted by the members of the structure? Probably this will depend on the weight of the load and the form of the structure. You might next visualize various configurations by means of which the desired results could be obtained. Since each material is most effective when used in a certain form, the decisions on form and materials must go hand in hand. The selection of a material will be based on such factors as costs, strength, appearance, durability, and ease of maintenance. Having selected a material, the next question is: How much material will be required? This, of course, depends on the magnitude or size of the forces in the members of the support.

This type of problem is quite common in engineering design. It requires for its solution a knowledge of the properties of materials, knowledge of the forces which are developed in loaded structures, and skill and judgment in combining the two in economic design. The courses in materials and mechanics were discussed briefly in the chapter on the Engineering Curriculum. The purpose of this chapter is twofold: first, to provide a preview of materials and elementary mechanics to illustrate the type of work that is done in courses in engineering science; second, to provide a technical background for more practice in problem solving.

MATERIALS

Materials constitute one great group of natural resources, and the engineer has the responsibility for transforming raw materials into vacuum tubes, automobiles, or a Grand Coulee Dam. Because materials are an important part of every engineering project, a knowledge of the properties and behavior of materials is an essential part of every engineer's training. This knowledge must be factual—based on careful observation and experimentation. It must be quantitative—it isn't enough to say that steel is strong. How strong is it? And this knowledge must be based on an understanding of the basic laws which govern the behavior of materials under the action of physical loads, chemical agents, heat, sunlight, and other natural forces.

Properties of Materials

Some of the common engineering materials such as stone, wood, copper, and clay products have been used for hundreds of years. However, their use was based on trial and error, and the successful projects indicate the remarkable skill of the builders. Only in the last three centuries have we made much progress toward formulation of the principles underlying the performance of materials. We now have a fairly good understanding of the behavior of metals, concrete, wood, and masonry under load, but there is much to be learned about the physical properties of rubber, plastics, and soils.

In the near future we should be able to predict the behavior of a material from the properties of its constituents and the physical processes in its formation. We do know that the properties of a material are dependent upon *chemical composition* and *physical arrangement*. Graphite and diamond are both forms of pure carbon, but the strong atomic bonds of the diamond account for its hardness and high electrical resistance. On the other hand, lead and aluminum have the same type of physical structure, but their properties differ because of their different chemical composition.

The modern theory of the structure of materials stipulates that all elements are composed of atoms, each atom consisting of a positively charged nucleus surrounded by planetary, negatively charged electrons. The arrangement of the planetary electrons has been utilized in making up the periodic chart which provides for 92 natural elements plus the recent man-made elements. The number of electrons in the atoms of an element determines its chemical properties, while the physical properties are dependent upon the arrangement of the atoms as well.

Materials are composed of many small units. Concrete is made up of a mass of sand and small rocks cemented together. Many building stones are composed of small particles cemented together naturally. Wood consists of fibers and cells which in turn are composed of molecules made up of atoms. Metals are made up of many individual crystals or grains which vary in composition and orientation. The properties of any engineering material are statistical averages of the corresponding properties of the individual units.

Behavior of Materials under Load

What actually happens when a steel member is loaded in tension? Consider a bar ½ by ¼ in. supporting a load of 1 ton. Making an imaginary cut through the bar as shown, the upward force on the section must just equal the downward force on the bar if the bar is to stay in place. The upward force must be developed across the section and will be distributed approximately uniformly if the material is homogeneous. The force per unit area (intensity of force) is called the *stress*, and the *average stress* is given by the equation

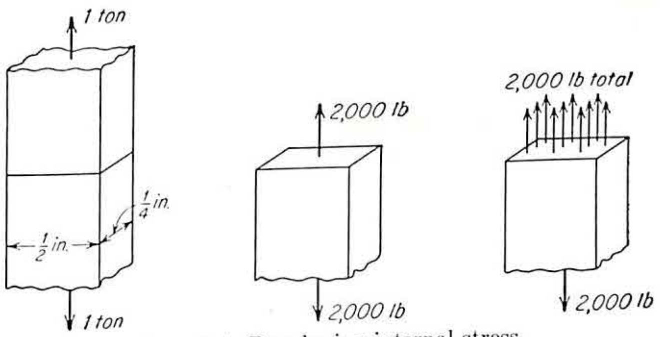


FIG. 16-1. Developing internal stress.

$$s = \frac{P}{A}$$

where s = stress in pounds per square inch (psi)
P = total force, lb
A = area, sq in.

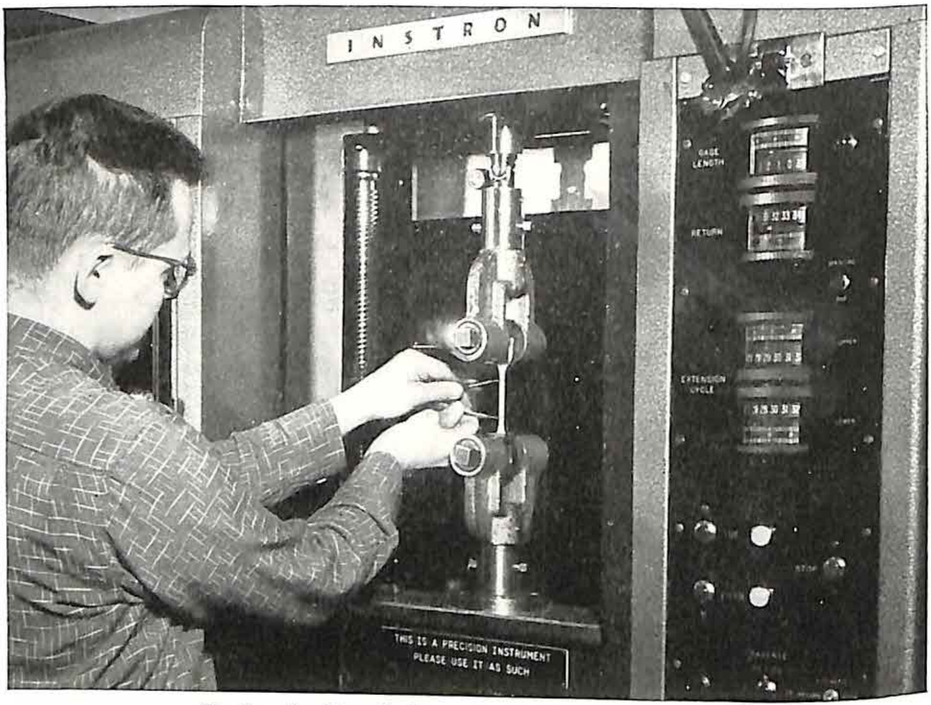
In the illustration, $s = 2{,}000/(\frac{1}{2} \times \frac{1}{4}) = 16{,}000$ psi.

As load is applied, the individual crystals are distorted or *strained* and in that way develop the resisting forces which hold the material together. The total strain or *elongation* is the amount by which the whole bar lengthens. The elongation per inch is called the unit strain and is given by the equation

$$\epsilon = \frac{e}{l}$$

where ϵ = strain or unit strain, in. per in.
e = total elongation, in.
l = length over which elongation occurs, in.

Stress-Strain Diagrams. Some of the important physical properties which are used by engineers may be obtained from a graph of the relationship between stress and strain. The graph is plotted from data obtained with a testing machine. The machine applies and measures loads which are converted to stresses by dividing by the area of the test specimen. The total deformations are measured by some form of gage, and these readings are converted to unit strain by dividing by the test length. The curve in Fig. 16-2 indicates that for a concrete cylinder in compression, the shortening increased slowly with load and then more rapidly until the specimen failed at a stress of 3,500 psi and a unit strain of 0.0021. The steel tensile bar (Fig. 16-3) lengthened uniformly with load up to about 32,000 psi and then elongated rapidly with no increase in load. This



Testing the Tensile Strength of Polyethylene Plastic

This precision testing machine rapidly determines the physical properties of materials. The specimen is mounted between the upper (fixed) and lower (movable) heads. As the lower head moves downward, it applies a measured load on the specimen; the stress can be calculated and the strain measured to determine modulus of elasticity and strength. Larger testing machines can apply loads of more than 1,000,000 lb to large structural elements. (*Monsanto Chemical Company.*)

phenomenon of *yielding*, or *plastic deformation*, is characteristic of *ductile* materials and is due to the sliding of part of a material past the adjacent material.

Elasticity. Over the straight portion of these curves, the stress is directly proportional to the strain. This is similar to the behavior of a spring and is called *elastic action* because if the stress is removed, the material returns to its original dimensions. In the elastic region, the proportionality can be expressed by the equation

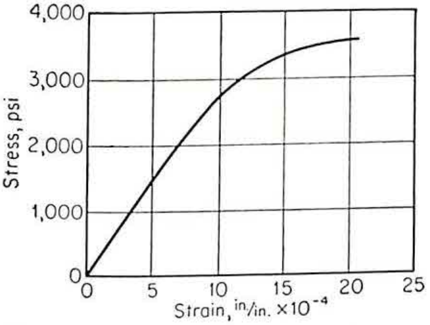


FIG. 16-2. Concrete in compression.

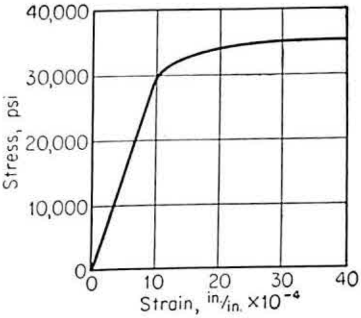


FIG. 16-3. Steel in tension.

$$s = E\epsilon$$

where E is the constant of proportionality and is called the *modulus of elasticity* (measured in pounds per square inch). The curve for concrete is straight up past a stress of 1,500 psi at a strain of 0.0005 in. per in. Therefore the modulus of elasticity E is approximately

$$1{,}500/0.0005 = 3{,}000{,}000 \text{ psi}$$

What is the modulus of elasticity for the steel specimen?

EXAMPLE: A steel tensile member is 10 ft long and ½ by 3 in. in cross section. If the modulus of elasticity of steel is 30 million psi, find the stress, strain, and total elongation of the member under a load of 24,000 lb.

$$s = \frac{P}{A} = \frac{24{,}000 \text{ lb}}{\frac{1}{2} \text{ in.} \times 3 \text{ in.}} = 16{,}000 \text{ psi}$$

Since $s = E\epsilon$,

$$\epsilon = \frac{s}{E} = \frac{16{,}000 \text{ psi}}{30{,}000{,}000 \text{ psi}} = 0.00053 \text{ in./in.}$$

Since $\epsilon = e/l$,

$$e = \epsilon l = 0.00053 \text{ in./in.} \times 10 \text{ ft} \times 12 \text{ in./ft} = 0.064 \text{ in.}$$

Failure of Materials

When a structural element ceases to function properly, it is said to have *failed*. Failure may be by chemical action as in corrosion or electrolysis or by physical action such as wear, deformation, or fracture. A brittle material may serve satisfactorily right up to the point of complete fracture. A rotating shaft, however, is said to have failed if it merely bends slightly out of line.

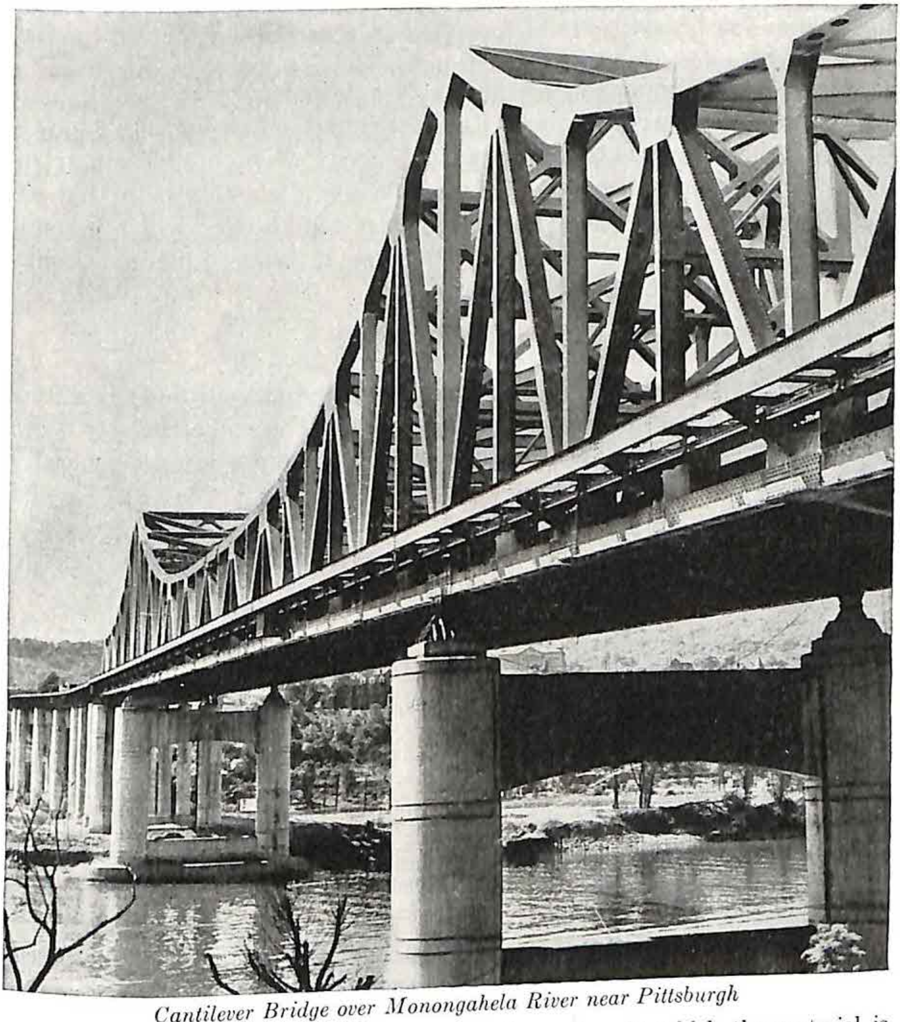
Failure caused by physical loads is common in engineering materials and merits a brief discussion as background for the discussion of mechanics which follows. Loads can be classified in terms of the way in which the loads are applied. *Continuous* loads are those which are applied for a long time such as the weight of the structure itself. A changing load may be considered as a continuous load if it is *slowly applied* with no shock or vibration. A *dynamic* or impact load exists if a body is suddenly dropped on a beam or if all persons in a grandstand suddenly rise to their feet. *Repeated* loading exists when the load is applied many times as in a vibrating, rotating, or reciprocating action. The magnitude of the load which can be supported by a given element depends on the type of loading. Special allowances must be made for dynamic or repeated loads.

Allowable Working Stresses

After the structural designer has decided on the general type of structure and the arrangement of the components, he must design each part to serve a certain purpose. In addition to meeting the requirements of appearance, cost, and weight, the member must be safe—able to withstand all the forces to which it may be subjected and still function properly.

The first step is to translate the loads carried by the structure into forces in each individual member. This is done by applying the principles of engineering mechanics. The next step is to select materials, shapes, and sizes to fit the predicted forces. For example, steel is a good material for a permanent installation where great strength is required and weight is not too critical. An I beam is an excellent shape for resisting bending loads because the material is concentrated at the top and bottom where it is most effective.

In determining the size of a member to resist a certain force, the cross-sectional area must be great enough to keep the stresses below a safe maximum. For example, the American Society for Testing Materials specifies that structural steel shall have a yield point (the bend in the stress-strain diagram) of at least 33,000 psi. While a tensile member in a bridge truss could function right up to the yield point, the maximum stress which can be used in design calculations is usually set at 18,000 psi.



Cantilever Bridge over Monongahela River near Pittsburgh

The steel truss is a configuration of structural members in which the material is worked very efficiently. The compression members are box girders and the tension members are I beams. Can you identify each? A passing train represents a variable load which, along with the dead weight of the bridge and tracks, must be carried by the reinforced-concrete piers. (*United States Steel Corporation.*)

This *allowable working stress* provides a liberal margin of stress to take care of such factors as variation in the strength of individual bars of steel, differences between the actual stresses in the completed structure and those calculated in the design, and the possibility of future loadings greater than those planned. The ratio of the strength of the material as specified to the maximum calculated stress is called the *factor of safety.* The factor of safety used in a given case will depend on the characteristics of the material and the damage which might result from failure.

MECHANICS

As indicated previously, mechanics is a broad subject dealing with forces and the behavior of bodies under the action of various types of forces. It includes mechanics of rigid bodies, mechanics of materials, mechanics of fluids, aerodynamics, and theory of elasticity. In this discussion, emphasis will be on the mechanics of rigid bodies, which is sometimes called theoretical mechanics because it treats idealized bodies which do not change shape under load.

Force

A force is a push or a pull. The pull of gravity on your body is a force called your weight which is measured by a scale. The pull of gravity is due to the mutual attraction between the earth and your body. In general, *a force is the action of one body on another.*

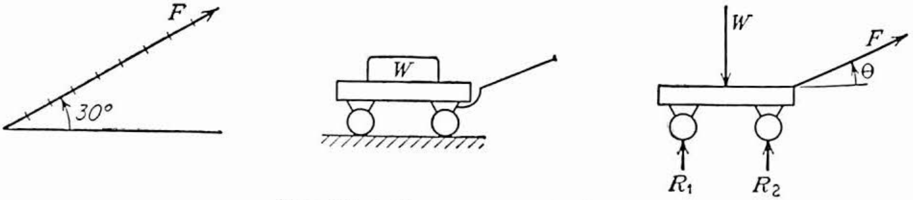


FIG. 16-4. Force representation.

The action of gravity is always downward, while other forces may act in any direction. Quantities which have both magnitude and direction are called *vectors*. Quantities which have only magnitude are called *scalars*. Examples of scalar quantities include volume, area, temperature, and energy. Vector quantities include force, velocity, momentum, and slope.

In completely defining a force, its magnitude, direction, and its point of application or line of action must be stipulated. It is convenient to represent a force by an arrow pointed in the given direction with the length of the arrow corresponding to the magnitude. In Fig. 16-4, the 10-lb force F exerted on the wagon is represented by an arrow 10 units long directed as shown. Other forces acting on the wagon include its weight W and the push, or *reaction*, of the ground on the wheels R_1 and R_2.

If an unbalanced force exists on the wagon, it will tend to move in the direction of the force. A common problem in engineering is the addition of various forces to find the *resultant*, the one force which is equivalent to the total of the individual forces. Scalar quantities can be added arithmetically; for example, 10 gal added to 8 gal equals 18 gal, or a drop of 6° added to a temperature of 93° equals 87°. However, a force of 10 lb added to a force of 8 lb may result in a force of 18 lb or a force of 2 lb or anything in between, depending on the directions of the forces. Vectors must be added *vectorially*, taking into account both magnitude and direction.

To illustrate vector addition, consider the following examples of forces acting on a body. In Fig. 16-5*a*, the sum of the two forces is +4 + 3, or 7 lb, since they have the same direction. In Fig. 16-5*b*, the resultant is

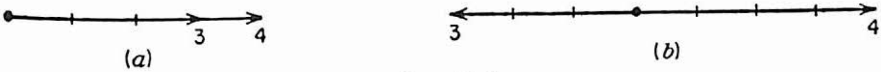


FIG. 16-5

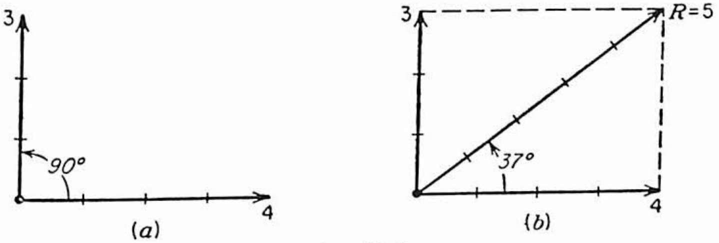


FIG. 16-6

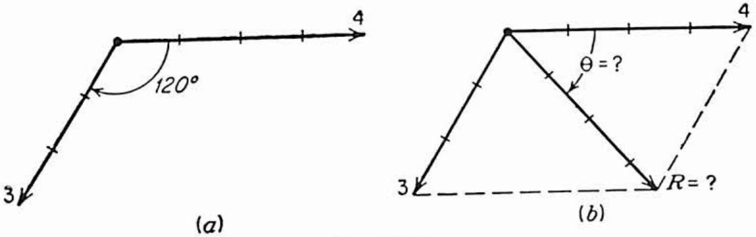


FIG. 16-7

+4 − 3, or 1 lb, since the 3-lb force is directed oppositely or negatively. In Fig. 16-6, the resultant can be found by the *parallelogram method* which states that *the resultant of any two forces is given by the diagonal of the parallelogram based on the two vectors*. With sides of 3 and 4 units, the diagonal is scaled off to be 5 units; therefore the resultant is 5 lb at an angle of +37°. What is the resultant in Fig. 16-7? Lay the forces off to scale in the indicated direction, complete the parallelogram, scale off the length of the resultant, and read the angle with a protractor.

A more general method, called the *polygon method*, can be used with any number of forces. In this method the forces are laid off to scale and in the correct direction with the tail of one placed to the tip of the previous one. In Fig. 16-8 (page 256), F_1 is laid off and then F_2. If a parallelogram were constructed, its diagonal would be the dotted line R_{12}; in other words, the resultant of forces F_1 and F_2 is the *line required to close the polygon* (a triangle in this case). Similarly, R_{123} is the resultant of R_{12} and F_3 or the resultant of F_1, F_2, and F_3. After adding on F_4, the line closing the polygon is R, or R is the equivalent of the four forces.

Consider the map (Fig. 16-9) showing vector trips. To go from the corner of 7th and E Streets to the bank at 1st and A Streets, you might walk north 1 block, across the park, north 1 block, then west 4 blocks.

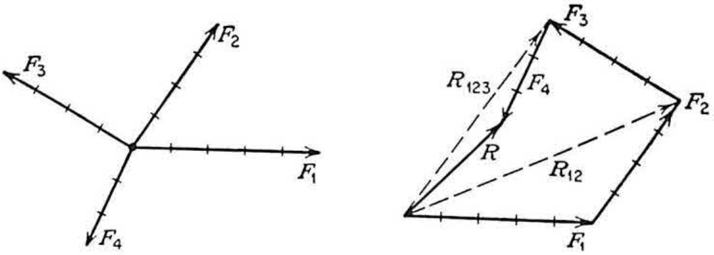


FIG. 16-8. The force polygon.

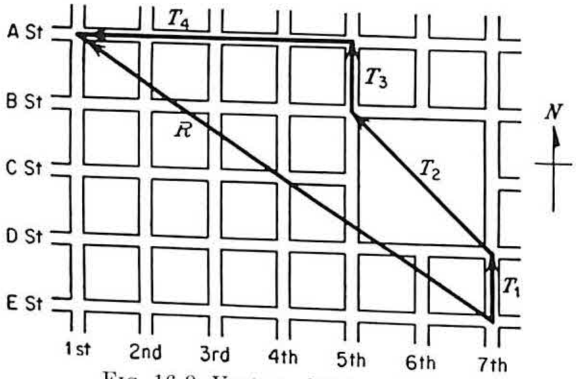


FIG. 16-9. Vector addition of trips.

The total trip, the resultant trip, is indicated by R and could be scaled off to be approximately 7¾ blocks in a direction N 56° W. Notice that the individual trips could be taken in any sequence. Vectorially speaking, $T_1 + T_2 + T_3 + T_4 = R$.

Resolution of Forces

In working with forces the two basic operations are the *addition* of forces to obtain the resultant and the *resolution* of forces into their components. Given the force F directed as shown in Fig. 16-10*a*, it can be resolved into two or more components so long as the vector sum of the components equals the original force. In Fig. 16-10*b*, components are taken along the lines *oa* and *ob* which are called *axes*. The component of F measured along the *a* axis is called F_a, read "F-subscript-a" or "F-sub-a."

In most practical problems it is convenient to take the axes at right angles to one another, the x axis being horizontal and the y axis vertical. Working with right-angle triangles makes it possible to use the Pythagorean theorem and the trigonometric functions. In Fig. 16-10c, the horizontal and vertical components are F_x and F_y, respectively. By the Pythagorean theorem,

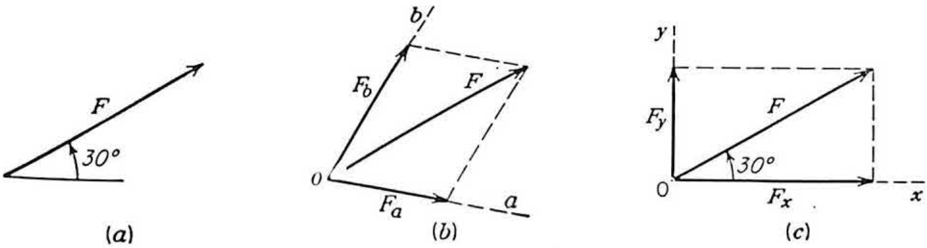


FIG. 16-10. Resolution of a force into components.

$$(F_x)^2 + (F_y)^2 = F^2$$

and by trigonometry,

$$F_x = F \cos 30° \qquad \text{and} \qquad F_y = F \sin 30°$$

To illustrate how the method of components can be used in vector problems, consider the two forces A and B in Fig. 16-11. By the parallelogram method, the resultant is given by R. The horizontal component of R is $R_x = A_x + B_x$; the vertical component of R is $R_y = A_y + B_y$. Also $R^2 = R_x^2 + R_y^2$. Therefore, to find the resultant of two or more forces, resolve the individual forces into x and y components, add the components algebraically to find the components of the resultant, and combine by the Pythagorean theorem. By working in terms of components, vector problems can be handled by algebra and trigonometry.

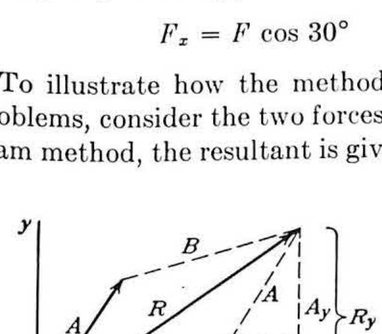


FIG. 16-11. Addition of components.

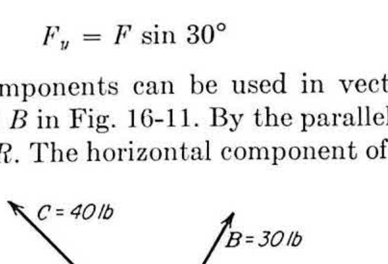


FIG. 16-12. Three-force system.

EXAMPLE: Given the system of three forces shown in Fig. 16-12. Find the resultant.

Force-polygon Method. This method is indicated in Fig. 16-13. Force A is drawn as a vector 50 units long at an angle of 30° below the horizontal. From the tip of A, B is drawn to scale. C is then added on. The resultant R is represented by the line required to close the figure. Its magnitude is scaled off as 42 lb at an angle $\theta = 45°$.

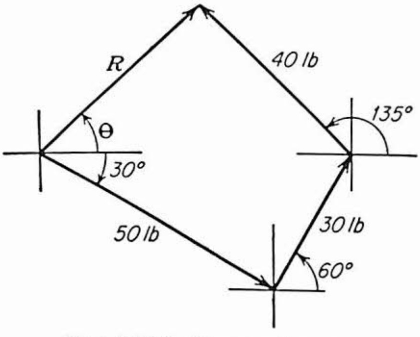


FIG. 16-13. Force polygon.

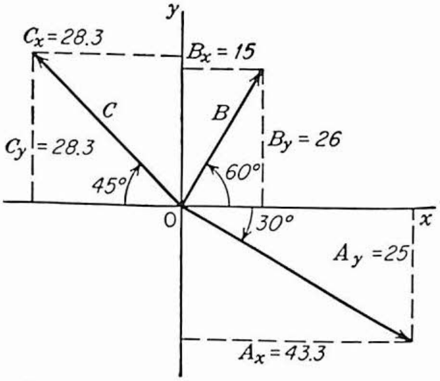


FIG. 16-14. Method of components.

Method of Components. In Fig. 16-14 the forces are drawn to scale and resolved into horizontal and vertical components. The components are scaled off as follows:

Force	X component	Y component
A	$+43.3$	-25.0
B	$+15.0$	$+26.0$
C	-28.3	$+28.3$
R	$+30.0$	$+29.3$

Components to the right and upward from the origin O are considered positive; to the left and downward, negative.

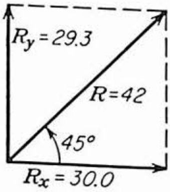


FIG. 16-15. Scaling the resultant.

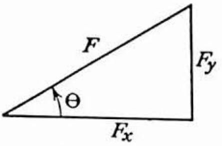


FIG. 16-16

Note that the x component of the resultant is the sum of the horizontal components of the three forces. If the x and y components of the resultant are laid off to scale as in Fig. 16-15, the resultant is again found to be 42 lb at an angle of 45° (approximately).

Analytical Method. Using trigonometry, the resultant can be found without scale plotting by recalling that in a right triangle (Fig. 16-16),

$$\sin \theta = \frac{F_y}{F} \quad \text{or} \quad F_y = F \sin \theta$$

$$\cos \theta = \frac{F_x}{F} \quad \text{or} \quad F_x = F \cos \theta$$

and

$$\tan \theta = \frac{F_y}{F_x} \quad \text{or} \quad \theta = \arctan \frac{F_y}{F_x}$$

where sin θ, cos θ, and tan θ are obtained from tables or slide rule.

In the example:

Force	X component	Y component
A	$+50 \cos 30° = +43.3$	$-50 \sin 30° = -25.0$
B	$+30 \cos 60° = +15.0$	$+30 \sin 60° = +26.0$
C	$-40 \cos 45° = -28.3$	$+40 \sin 45° = +28.3$
R	$+30.0$	$+29.3$

$$R = \sqrt{R_x^2 + R_y^2} = \sqrt{30.0^2 + 29.3^2} = \sqrt{1758.5} = 41.9 \text{ lb}$$

$$\theta = \arctan \frac{29.3}{30.0} = 44.4°$$

Each of these three methods has its own particular advantages in engineering problems. One may be used as a check on another.

Forces in Equilibrium

A body is said to be in equilibrium if it is at rest or if it is moving with a constant speed in a straight line. For a body to be in equilibrium, there must be no unbalanced forces acting on it; in other words, the resultant of all the forces acting on it must be zero. For the special case where all the forces act through a common point, the resultant will be zero if both the x component and the y component of the resultant are zero. This will be true if the sum of the x components of all the individual forces is zero and the sum of the y components of all the forces is zero. This can be expressed graphically by saying that the force polygon must be a closed figure, or analytically by saying sum $F_x = 0$ and sum $F_y = 0$.

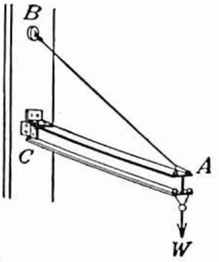


FIG. 16-17. Structure in equilibrium.

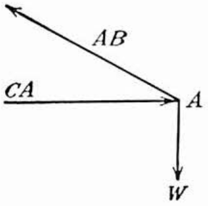


FIG. 16-18. Forces in equilibrium.

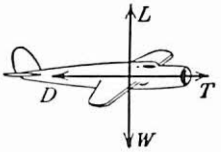


FIG. 16-19. Airplane in equilibrium.

The two structural members AB and CA support the weight W. Since point A does not move, it is in equilibrium and the weight W and the forces in the members CA and AB must add up to zero. Similarly, in an airplane flying at constant velocity, the vector sum of the forces of gravity W, thrust T, lift L, and drag D must be zero.

EXAMPLE: Given a weight of 300 lb (Fig. 16-20) supported by a horizonal force A and a force B directed 30° above the horizontal. Find the forces A and B.

Since the weight is "supported," it must be in equilibrium and therefore the sum of the forces must be zero.

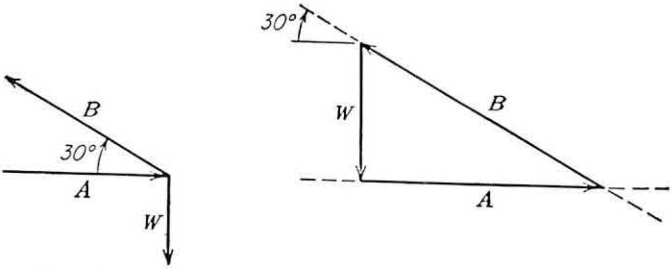


FIG. 16-20. Graphical solution of equilibrium problem.

The force W is drawn vertical to scale. The directions of the other two forces are known, but their magnitudes are to be found. Since the sum of the forces is zero, the force vectors must form a closed polygon (a triangle in this case of only three forces). The direction of A is indicated by a horizontal line of indeterminate length through the tip of W. From some point on that line, another vector must go at an angle of 30° to the tail of W. Therefore from the tail of W draw a line of indeterminate length at an angle of 30° with the horizontal. The intersection of these two construction lines determines the lengths of B and A which are scaled off as 600 and 520 lb, respectively.

Analytically, this problem could be solved as follows:

Since the weight is in equilibrium,

$$\text{Sum } F_x = 0 = A - B\cos 30^\circ = A - 0.866B \qquad (1)$$

and

$$\text{Sum } F_y = 0 = -W + B\sin 30^\circ = -W + 0.5B \qquad (2)$$

From (2)

$$B = \frac{W}{0.5} = \frac{300}{0.5} = 600 \text{ lb}$$

Substituting in (1) $A = 0.866B = 0.866 \times 600 = 520$ lb

The Lever and Moments

Archimedes' principle of the lever is one of the fundamentals of mechanics. It says that when a beam is in balance over a fulcrum, the forces are inversely proportional to their distances from the fulcrum. Expressed mathematically, $A \times a = B \times b$.

This product of a force A and a distance a is a measure of a tendency to turn, and it is called a *torque* or *moment*. In general, the moment of a force about any axis is the product of the force times the perpendicular distance (moment arm) from the axis to the line of action of the force. In Fig. 16-22, the 10-lb force exerts a moment of 10 lb × 2 ft, or 20 lb-ft, about the axis at A. The 20-lb force exerts a moment of 20 lb × 2.83 ft = 56.6 lb-ft. What moment is exerted by the 5-lb force? The 15-lb force? What is the moment of the 15-lb force about point B?

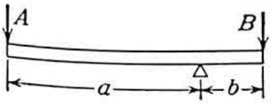


Fig. 16-21. The lever.

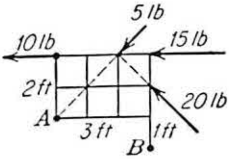


Fig. 16-22. Moments.

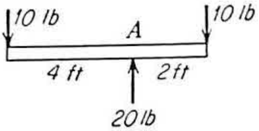


Fig. 16-23. Unbalanced moments.

Now consider the system of forces in Fig. 16-23 which do not all pass through the same point. Are the forces in equilibrium? Checking, Sum $F = +20 - 10 - 10 = 0$, so there is no resultant tendency to move up or down. But checking the moments about point A, there is a moment of $10 \times 4 = 40$ lb-ft tending to turn counterclockwise (positive) and a moment of $10 \times 2 = 20$ lb-ft tending to turn clockwise (negative). Therefore, there is an unbalanced moment of $40 - 20 = 20$ lb-ft, and the beam is not in equilibrium. In general, then, the defining equations for equilibrium are

$$\text{Sum } F_x = 0$$

$$\text{Sum } F_y = 0$$

and

$$\text{Sum } M_A = 0$$

where A is any axis.

Example: A beam of negligible weight rests on supports 12 ft apart and carries loads as shown. Find the forces on the supports.

The action of the loaded beam on the supports produces reactions in the supports which hold the beam in equilibrium. The forces acting *on* the beam are as shown in Fig. 16-24*b*, which is called a *free-body diagram*. It is often helpful to select a part of the structure under consideration, draw the free-body diagram showing the forces acting *on* that part, and write the corresponding equilibrium equations.

Since the beam is in equilibrium

$$\text{Sum } M_A = 0 = +R_B \times 12 - 100 \times 3 - 300 \times 8$$

$$= 12R_B - 300 - 2{,}400$$

Solving,

$$R_B = \frac{2{,}700}{12} = 225 \text{ lb}$$

Note that by taking moments about A, the unknown force through A was eliminated, since it contributed no moment. Similarly

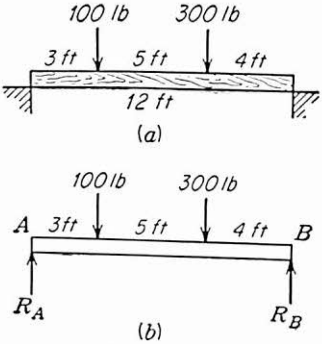


FIG. 16-24. Loaded beam.

$$\begin{aligned} \text{Sum } M_B = 0 &= +300 \times 4 + 100 \times 9 \\ &\quad - R_A \times 12 = 2{,}100 - R_A \times 12 \end{aligned}$$

Solving,

$$R_A = \frac{2{,}100}{12} = 175 \text{ lb}$$

For a check, use another condition of equilibrium;

$$\begin{aligned} \text{Sum } F_y = 0 &= R_A - 100 - 300 + R_B \\ &= 175 - 100 - 300 + 225 = 0 \end{aligned}$$

Solution of Practical Problems

Theoretical mechanics deals with idealized systems involving rigid bodies and weightless members. The principles of mechanics can be applied to practical problems after the necessary simplifying assumptions have been made. Consider the problem suggested in the introduction to this chapter.

PROBLEM: Out in the shop a heavy piece of equipment must be swung horizontally through a 6-ft radius; design a suitable crane.

1. Preliminary Analysis. The solution to this problem will be in the form of a sketch specifying the necessary structural members. The problem involves selection of materials, sizes, and shapes. The selection should be on the basis of economy and safety. The size of the members will depend on the forces involved, which in turn depend on the weight of the load. The shapes specified should be standard items in order to keep the cost down.

2. Statement. After some reflection and obtaining information from various sources it is determined that

The equipment to be supported weighs approximately 4 tons.

There is available a selection of structural timbers and steel angles.

A heavy structural column in the building can be used as a mast.

A satisfactory design would consist of a timber beam and steel angle as shown.

The allowable design stress for Douglas fir under these conditions would be approximately 900 psi and for steel approximately 18,000 psi.

The design of metal connectors and the hinge is not a part of this problem.

The following simplifying assumptions appear reasonable:

Assume that the weight of the structural members is negligible compared with the weight of the load.

Assume that the members are in pure tension or compression with no bending.

Assume that, under load, the members do not deform enough to distort the structure.

Assume design stresses of 900 and 18,000 psi for the wood and steel, respectively.

The simplified problem can now be stated:

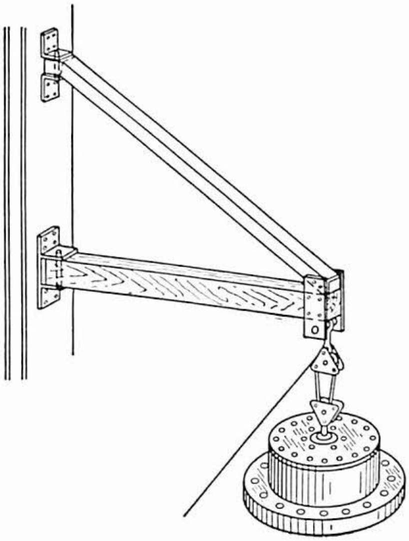


FIG. 16-25. Proposed design.

a. Given a weightless truss loaded as shown, what are the forces in members *AB* and *AC*?

b. To withstand these forces, what cross-sectional area of steel and wood should be used for each member ($S_w = 900$ psi, $S_s = 18{,}000$ psi)? (A guess at this stage will serve as a check later. What do you estimate will be the sizes required?)

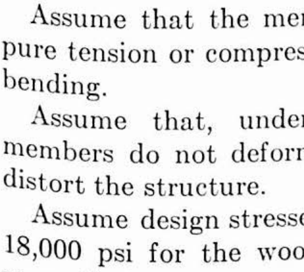


FIG. 16-26. Idealized problem.

3. Solution. *a*. Consider the beam as a *free body* with the forces acting *on* it. (The moment arm of the force *AB* can be calculated trigonometrically as 6 sin 30° = 3 ft or scaled off graphically.)

Since member *AC* is in equilibrium, the sum of all the moments tending to turn it about point *C* must be zero. (Note that R_C, the reaction of the wall, produces no turning effect about point *C*.) Therefore,

$$\text{Sum } M_C = 0 = +AB \times 3 - 8{,}000 \times 6$$

Solving,
$$AB = \frac{48{,}000}{3} = 16{,}000 \text{ lb tension}$$

Now consider point *A* as a free body. Since it is in equilibrium the sum of the forces on point *A* must be zero. Therefore,

$$\text{Sum } F_x = 0 = CA - 16{,}000 \cos 30^\circ$$

Solving, $CA = 16{,}000 \times 0.866 = 13{,}900$ lb compression

b. The required cross-sectional area for the members can be calculated from

$$s = \frac{P}{A} \qquad \text{or} \qquad A = \frac{P}{s}$$

where P = force, lb
s = stress, psi
A = area, sq in.

For member AB, $A = \dfrac{16{,}000}{18{,}000} = 0.89$ sq in.

For member CA, $A = \dfrac{13{,}900}{900} = 15.5$ sq in.

4. Check. (The guesses made earlier will constitute an intuitive check, although their value will depend on the amount of experience backing them up.)

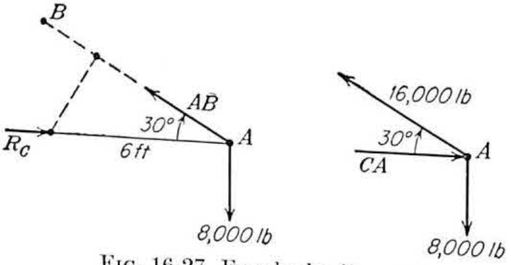


FIG. 16-27. Free-body diagrams.

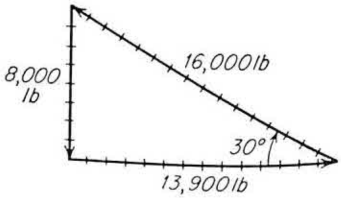


FIG. 16-28. Graphical check.

The forces were obtained analytically, and a good check would be a graphical solution. One approach would be to see if the forces form a closed triangle when plotted to scale (Fig. 16-28). Another approach would be to take moments about some new point, such as B.

The areas obtained could be compared with the sizes used in similar situations. What size block of wood can be used under an automobile jack without being crushed?

5. Interpretation. Examine again the assumptions made.

A 4- by 6-in. beam weighs only 4 or 5 lb per ft and 3- by 3- by 7⁄16-in. steel angle weighs only 8.3 lb per ft, so neglecting these weights had no appreciable effect on the answer.

If the ends of the supporting members are restrained, any bending stresses set up will contribute to the support of the load.

The deformation under design conditions is so small that neglecting it has no appreciable effect.

The design stresses used are conservative and include a safety factor.

However, some allowance should be made for the effect of cutting holes in the members to make the connections.

In selecting a beam to provide 15.5 sq in. of area, it is noted that a 4-by-4 is actually approximately $3\frac{5}{8}$ by $3\frac{5}{8}$ in. and the effective area is only 13.14 sq in. A 4-by-6 has an effective area of 20.40 sq in. A 6-by-6 has an effective area of 31.65 sq in. In selecting the proper steel angle, the tables offer the following:

Size, in.	Area, sq in.
$1\frac{1}{2} \times 1\frac{1}{2} \times \frac{3}{8}$	0.98
$1\frac{3}{4} \times 1\frac{3}{4} \times \frac{3}{8}$	1.17
$2 \times 2 \times \frac{3}{8}$	1.36
$2\frac{1}{2} \times 2\frac{1}{2} \times \frac{7}{16}$	2.00

After considering the sizes available and taking into consideration the losses in area due to cutting connection holes, *it is recommended that a 4-by-6 beam and a 2-by-2-by-$\frac{3}{8}$ angle be used.* (A sketch would be prepared showing the dimensions of the members, a layout of the necessary holes, and details for connecting to the mast.)

FRICTION

When two surfaces are rubbed together, the force that tends to oppose relative movement is called *friction.* Friction makes walking more difficult, but you cannot walk without friction. Engineers spend a lot of time trying to increase friction or trying to decrease friction. Can you name two places in an automobile where efforts are made to obtain high friction and two places where low friction is desirable?

EXPERIMENT A: To derive a quantitative basis for considering friction forces, perform the following experiment. Place the eraser end of a pencil on your desk top with your finger pushing on the other end. Slowly move the pencil out of the vertical position, and note the angle at which the eraser begins to slip along the desk. Repeat with greater and less force on the pencil. The angle will be found to be in the neighborhood of 30° and independent of the force.

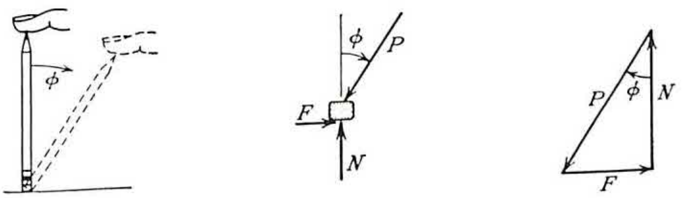


FIG. 16-29. An experiment with friction forces.

Considering the eraser as a free body, the forces acting on it are as shown. The angle ϕ at which slipping just begins is called the *friction angle*. The force parallel to the rubbing surfaces is called the friction force F, and the force perpendicular to the surfaces is called the normal force N. Since these forces are in equilibrium just before slipping begins, the sum of the forces must be zero or the three forces must form a closed triangle. The general relation is

$$F = N \tan \phi = fN$$

where f is the *coefficient of friction* and equals tangent ϕ.

EXPERIMENT B: Place a pencil on your notebook and slowly incline the notebook until the pencil just begins to slide. Note that the pencil continues to slide, in fact, picks up speed, if the angle ϕ is maintained. This demonstrates two principles of friction: First, ϕ is again the friction angle, and second, the coefficient of sliding friction is usually smaller than the coefficient of starting friction. Analyzing the forces on the pencil as a free body and remembering that N is the force normal to the rubbing surface, it is seen that

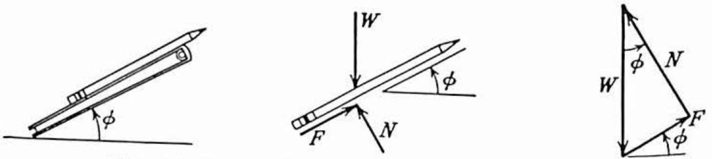


FIG. 16-30. Another experiment with friction.

$$F = N \tan \phi = fN \text{ as before}$$

Repeat this experiment with a rubber eraser, and determine the coefficient of friction between rubber and your notebook cover.

Coefficients of Friction. In general there are four types of friction: *starting, sliding, rolling,* and *fluid* friction. Values of f are greatly affected by the conditions of test and usually must be determined experimentally. Typical values for starting friction coefficients are as follows:

Metal on wood	0.6
Wood on wood	0.4
Steel on steel	0.2
Rubber tire on dry asphalt	0.5

Typical values of sliding friction coefficients are as follows:

Metal sled runners on ice	0.02
Wood sled runners on ice	0.035
Asbestos brake lining on iron	0.3
Rubber tire on dry asphalt	0.4

Rolling friction coefficients depend on the radius of the rollers and are usually much lower than for sliding. For example:

1-in. steel rollers on clean steel	0.0005
1-in. steel rollers on rusty steel	0.0030
Automobile tires on pavement	0.02
Automobile tires on loose sand	0.20

When bearings are properly lubricated, the surfaces are separated by a thin film of grease or oil. The friction is due to layers of lubricant sliding over each other and will be much less than for dry surfaces.

EXAMPLE: Consider the following simplified problem (step 3 in the general problem solution). Find the horizontal force required to start a 60-lb block up a 30° slope if the starting friction angle for the slope is 20° ($f = \tan 20° = 0.36$).

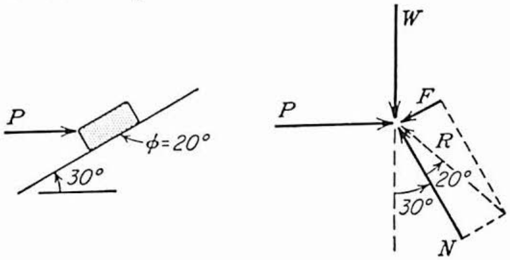


FIG. 16-31. Friction problem.

The forces acting on the block are as shown. Note that the effect of N and F can be combined into a resultant R. In solving this problem graphically, lay off the weight W to scale. Then indicate R at an angle of $30° + 20°$ but with an unknown magnitude. Since the block is in equilibrium just before sliding, the vector sum of W, R, and P must be zero. Therefore, a line (direction of P) is drawn horizontally through the tail of W, and its intersection with R determines the magnitude of P and R. P is scaled off to be approximately 70 lb. A good engineering prospect should be able to figure out the force P required to just *hold* the block on the slope. Can you? Remember that friction always acts in a direction so as to oppose relative motion.

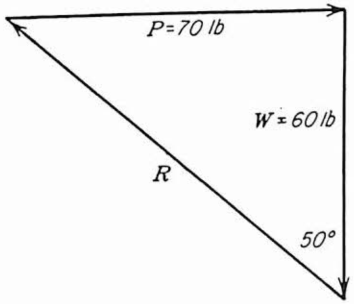


FIG. 16-32. Graphical solution.

DYNAMICS

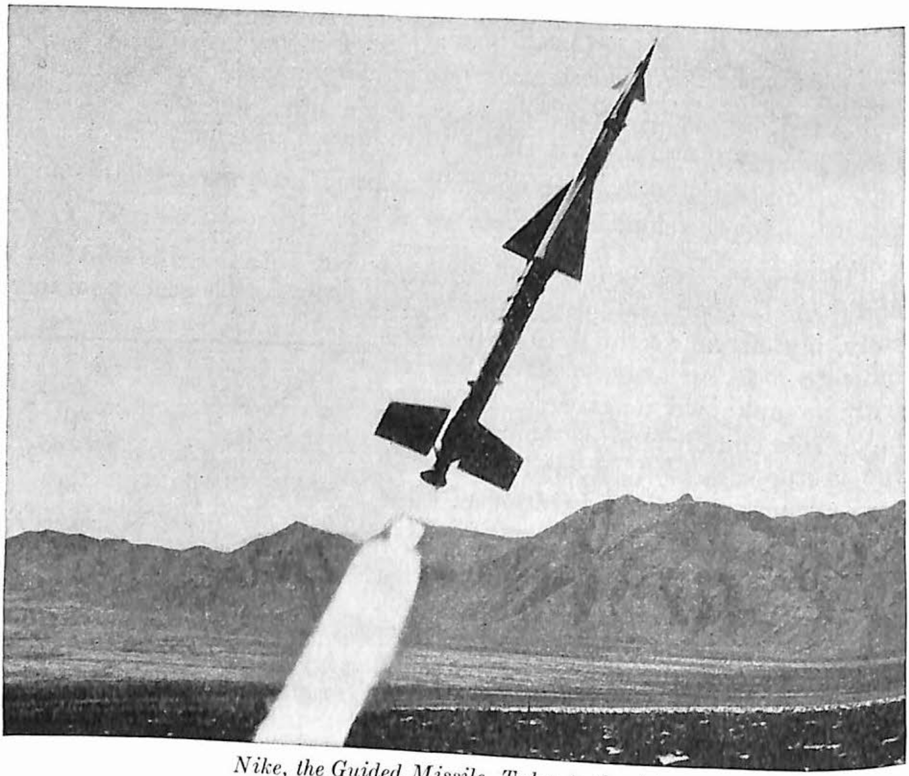
Another problem in friction is as follows: Find the force required to move a 20-lb sled carrying a 100-lb boy over level ice. The total normal force is 20 + 100 = 120 lb. If f is 0.02, the friction force is

$$F = fN = 0.02 \times 120 = 2.4 \text{ lb}$$

If a force of 2.4 lb is applied, the sled will move with a constant speed and the forces are in equilibrium. What will happen if a greater push is applied? Now there will be an unbalanced force, and in accordance with Newton's laws of motion, there will be an acceleration in the direction of the unbalanced force and proportional to it. Up to this point the discussion of mechanics has been limited to forces on stationary bodies and is generally called *statics*. The portion of mechanics dealing with bodies in motion is called *dynamics*.

Velocity

The speed of an automobile is distance traveled per unit of time, 60 mph, for example. When the direction also is specified, the rate of



Nike, the Guided Missile, Takes to the Air

This is a rocket-type missile in which the propellant is burned to produce a great volume of gas. The expansion of the gas forces it out the rear at high velocity. The acceleration of the gas rearward produces an equal and opposite thrust forward. The rocket carries its own supply of oxygen and does not depend on the atmosphere to develop its thrust as do propeller-driven aircraft, therefore it is capable of traveling at high altitudes or in interplanetary space. (*U.S. Army Photo.*)

travel is a vector, *velocity*. In other words, speed is the magnitude of velocity. Since velocity is a vector, velocities must be added vectorially. Suppose that a blimp headed north has an indicated air speed of 40 mph while flying in a 30-mph wind from the east. The resultant ground velocity will be 50 mph in the direction N 37° W. Sketch the vector diagram to illustrate this relationship.

Expressed algebraically,

$$v = \frac{s_f - s_o}{t} = \frac{s}{t}$$

where v = velocity (usually in feet per second in engineering)
s_f = final distance, ft
s_o = initial distance, ft
s = net distance traveled, ft
t = elapsed time, sec

Velocity may be a constant, unchanging with time, or a variable, changing with time. The quotient of the net distance divided by the total time gives an average velocity.

Acceleration

To change the velocity of an automobile you step on the "accelerator." Acceleration is the rate of change of velocity or the change in velocity per unit of time. Expressed algebraically

$$a = \frac{v_f - v_o}{t}$$

where a = average acceleration, ft per sec per sec or ft per sec^2
v_o = initial velocity, ft per sec
v_f = velocity after time t, ft per sec
t = elapsed time, sec

EXAMPLE: A certain rocket is traveling at a velocity of 400 ft per sec and 10 sec later has reached a velocity of 800 ft per sec. The average acceleration over the 10-sec interval is

$$a = \frac{800 - 400}{10} = \frac{400}{10} = 40 \text{ ft/sec}^2$$

Note that this is the actual acceleration only if the acceleration is constant during the interval. In general, acceleration is constant or variable, positive or negative. A negative acceleration indicates that the object is slowing down, going from a given velocity to a lower one.

Acceleration of Gravity

On the basis of inaccurate observations, the great philosopher Aristotle believed and taught that heavy bodies fall proportionately faster than light ones. This was accepted for nearly one thousand years until Galileo performed his famous experiment of dropping stones of various sizes from the Leaning Tower of Pisa. We now know that in a vacuum, a feather gains speed as rapidly as a rock.

Sir Isaac Newton's universal law of gravitation states that: Any two bodies attract each other with a force which is proportional to the product of their masses and inversely proportional to the square of the distance between them. The acceleration of a falling body is due to the mutual attraction between the body and the earth. This acceleration g varies slightly over the surface of the earth, being largest at the poles and least at the equator. A value of $g = 32.2$ ft per sec^2 is generally used for mean sea level in the United States.

In problems of falling bodies, the equation for final velocity becomes

$$v_f = v_o - gt$$

where the minus sign indicates that the pull of gravity is downward.

EXAMPLE: The velocity of a falling rock 5 sec after starting from rest is

$$v_f = 0 - 32.2 \times 5 = -161 \text{ ft/sec}$$

if the effect of air resistance is neglected. If a rock is thrown upward with a velocity of 40 ft per sec, its velocity after 3 sec is

$$v_f = +40 - 32.2 \times 3 = -56.6 \text{ ft/sec}$$

Distance

The distance traveled at a constant velocity during a specified time is given by the equation

$$s = vt$$

If the velocity is changing, the effect of the acceleration must be taken into account. If the acceleration is constant, the change in velocity in a given time interval is

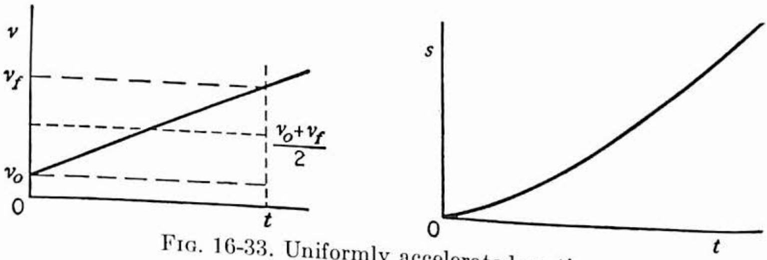


FIG. 16-33. Uniformly accelerated motion.

$$v_f - v_o = at$$

and the average velocity during the interval is

$$\frac{v_o + v_f}{2} = v_o + \frac{v_f - v_o}{2} = v_o + \frac{1}{2}\,at$$

The total distance traveled during constant acceleration will be

$$s = vt = v_o t + \tfrac{1}{2}at^2$$

Another relation between acceleration, velocity, and distance can be derived by noting that since

$$a = \frac{v_f - v_o}{t} \qquad t = \frac{v_f - v_o}{a}$$

Therefore,

$$s = v_o t + \frac{1}{2}\,at^2 = v_o\left(\frac{v_f - v_o}{a}\right) + \frac{1}{2}\,a\left(\frac{v_f - v_o}{a}\right)^2$$

Carrying out the indicated operations and collecting terms,

$$2as = v_f^2 - v_o^2 \qquad \text{or} \qquad v_f^2 = v_o^2 + 2as$$

EXAMPLE: A certain "hot" stock car will go from 30 to 60 mph in 5 sec. What is the average acceleration, and how far will it travel during that time?

Converting to the usual engineering units,

$$60 \text{ mph} = 60 \times \frac{5{,}280 \text{ ft/mi}}{3{,}600 \text{ sec/hr}} = 88 \text{ ft/sec and } 30 \text{ mph} = 44 \text{ ft/sec}$$

$$\text{Therefore,} \quad a = \frac{v - v_o}{t} = \frac{88 - 44}{5} = 8.8 \text{ ft/sec}^2$$

Assuming constant acceleration,

$$s = v_o t + \tfrac{1}{2}at^2 = 44 \times 5 + \tfrac{1}{2} \times 8.8 \times 5^2 = 330 \text{ ft}$$

Newton's Second Law

What causes acceleration? Acceleration is due to an unbalanced force and, as stated by Newton, the acceleration is in the direction of the force and proportional to it. The constant of proportionality is called the *mass*. Expressed algebraically,

$$F = ma$$

where F = force, lb (in engineering)
a = acceleration, ft per sec^2
m = mass, slugs

What is a *slug?* Engineers are practical, and "lazy" in an efficient sort of sense; they do things the simplest way. Since many of the forces in engineering are due to loads, forces are expressed in the same units as weights. A carton of sugar labeled "one pound" contains a certain *amount* of sugar which when accelerated by gravity develops a force of 1 lb. But weight depends on acceleration and is not a constant; the carton of sugar when weighed on a spring scale in an elevator accelerating downward at 16.1 ft per sec^2 will weigh only 0.5 lb. If the elevator accelerates upward at 16.1 ft per sec^2, the carton will weigh 1.5 lb. On the moon the carton would weigh only ⅙ lb.

The amount of sugar, or the *mass*, is constant under all conditions. The unit of mass, the slug, is defined as the amount of matter which is accelerated 1 ft per sec^2 by a force of 1 lb. Since a force equal to the weight of an object gives it the acceleration of gravity, to convert weight in pounds to mass in slugs, divide the gravitational constant, or

$$m = \frac{\text{force}}{\text{acceleration}} = \frac{W}{g}$$

EXAMPLE: If the "hot" stock car of the preceding example weighs 3,800 lb, how much net thrust must be developed at the rear wheels to provide the indicated performance?

$$F = ma = \frac{W}{g}a = \frac{3{,}800}{32.2} \times 8.8 = 1{,}040 \text{ lb thrust}$$

In addition the car must develop thrust to overcome the resisting forces of rolling friction and air friction.

WORK, ENERGY, AND POWER

The natural resources which engineers convert into useful products can be subdivided into materials and energies. In a restricted sense, energy is the ability to do work while power is the rate of doing work.

Work

To a child all activity is either work or play. An engineering student will refer to his mental exercises as home "work" but classify a mountain climb as "play." The dictionary definition of work includes "that which is accomplished as a result of exertion." The engineer is usually concerned with mechanical work which is motion as a result of applied force; in this sense, *work is measured by force times distance moved in the direction of the force.*

A simple illustration would be the work done in lifting a 40-lb weight through a vertical distance of 3 ft. Here

$$\text{Work} = \text{force} \times \text{distance} = 40 \text{ lb} \times 3 \text{ ft} = 120 \text{ ft-lb}$$

Since this work is done against the force of gravity, the distance must be measured vertically.

If the 40-lb weight is carried by a 160-lb man up a flight of stairs which rises 10 ft in a horizontal distance of 14 ft, what would be the work done? The work done *on* the weight *by* the man would be 40 lb × 10 ft = 400 ft-lb. The total work done by the man would be

$$(40 + 160) \text{ lb} \times 10 \text{ ft} = 2{,}000 \text{ ft-lb}$$

Supporting a weight or moving a weight horizontally involves no work even though the person doing it may get tired.

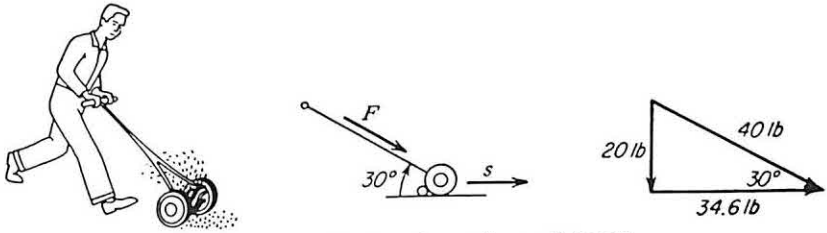


FIG. 16-34. Work as force times distance.

EXAMPLE: Calculate the work done in mowing a 50-ft strip of level lawn if a force of 40 lb is required when the handle is at an angle of 30° with the horizontal. The component of force in the direction of motion can be obtained graphically or trigonometrically. The work done is

$$W = F \times s = 34.6 \text{ lb} \times 50 \text{ ft} = 1{,}730 \text{ ft-lb}$$

Energy

To the engineer, energy is a means to an end, a means of accomplishing useful work. A majority of technical engineering problems are concerned with developing, generating, transmitting, and transforming energy in one form or another. Useful forms include heat, light, sound, and chemical, electrical, and mechanical energy. This discussion will emphasize mechanical energy, which includes potential energy and kinetic energy.

Potential Energy. Raise a 1-lb book to a height of 2 ft above your desk. In doing 2 ft-lb of work on the book, you have contributed 2 ft-lb of energy to the book. This energy exists as a result of its position with respect to the desk top; it is called *potential* energy because it is available to do work. Release the book, and it falls to the desk where its potential energy is converted into heat which warms the book and sound which may be used to awaken your dozing roommate. Note that work is energy in transition; energy can be stored, but work cannot.

Kinetic Energy. As the book started to fall, its energy of position, potential energy, was converted into energy of motion, *kinetic* energy. At a height of 1 ft, half of its total energy was potential, half kinetic. After it had fallen 2 ft all its potential energy had been converted into kinetic energy. By considering this energy conversion, an expression for kinetic energy can be derived in terms of quantities previously defined. In general

$$v_f - v_o = at \qquad \text{and} \qquad s = v_o t + \tfrac{1}{2}at^2$$

For the special case of falling from rest, $v_f = v$ (a variable), $v_o = 0$, and $a = g$. Therefore,

$$v = gt \qquad \text{and} \qquad s = \tfrac{1}{2}gt^2$$

or

$$t = \frac{v}{g} \qquad \text{and} \qquad s = \frac{1}{2}g\left(\frac{v}{g}\right)^2 = \frac{1}{2}\frac{v^2}{g}$$

This last equation gives the distance fallen s while attaining velocity v under the acceleration of gravity g.

The potential energy of a weight W at a height s is $W \times s$; if that potential energy is converted into kinetic energy,

$$\text{PE} = W \times s = W \times \frac{1}{2}\frac{v^2}{g} = \frac{1}{2}\frac{W}{g}v^2 = \frac{1}{2}mv^2 = \text{KE}$$

Therefore, we conclude that kinetic energy is equal to one-half the mass times the velocity squared. What are the units of kinetic energy?

EXAMPLE: Returning to the "hot" stock car, how much work is done on the car by the accelerating thrust? How much kinetic energy is gained during the acceleration?

Since work is force times distance,

$$W = F \times s = 1{,}040 \text{ lb} \times 330 \text{ ft} = 343{,}000 \text{ ft-lb}$$

The kinetic energy gained will be the energy at 60 mph minus the energy at 30 mph, or

$$\begin{aligned} \text{KE gained} &= \frac{1}{2}mv^2 - \frac{1}{2}mv_o^2 = \frac{1}{2}\frac{W}{g}(v^2 - v_o^2) \\ &= \frac{1}{2}\frac{3800}{32.2}(88^2 - 44^2) = 343{,}000 \text{ ft-lb} \end{aligned}$$

Conservation of Energy

As would be expected, the kinetic energy gained by the car is just equal to the work done on it. This is a special case of the very important *Law of Conservation of Energy*, which says that energy is never created nor destroyed but may be changed from one form to another. A simple illustration of conservation of mechanical energy is the pendulum. Work is done on the bob when it is raised to its initial height. As the pendulum swings down its initial potential energy is changed to kinetic energy which is a maximum at the bottom of the swing. Kinetic energy is then expended as the bob rises higher, and as it comes to rest at the top of the swing, the energy of motion has been converted back into energy of position. The height of the bob in this rest position is slightly less than the initial height, the difference representing energy dissipated in air and mechanical friction. But the friction energy is not lost; it has been converted into another form, heat. In a clock, the energy dissipated is supplied from the potential energy stored in the mainspring.

Efficiency

The engineer has the responsibility for devising methods for energy conversion with a maximum efficiency. In an electrical power system, the potential energy of water behind a dam is converted into the kinetic energy of a high-velocity stream and directed against the blades of a water turbine. The generator converts mechanical energy into electrical energy, which is transformed into high-voltage energy and transmitted to an industrial load center where it is stepped down to a safer voltage for distribution. In a given plant, the electrical energy is converted into mechanical, thermal, luminous, or chemical forms.

In each of these conversions, some energy is transformed into an undesirable form and is said to be "lost," although the engineer knows where it goes. Applying the Law of Conservation of Energy to any process,

$$\text{Input} = \text{output} + \text{losses}$$

By definition

$$\text{Efficiency} = \frac{\text{output}}{\text{input}} = \frac{\text{output}}{\text{output} + \text{losses}} = \frac{\text{input} - \text{losses}}{\text{input}}$$

The form of the equation to be used in any problem depends on which two of the three variables are obtainable most readily.

EXAMPLE: A pulley system has been rigged to raise a 5-ton load to a height of 10 ft. The force required of the operator is only 60 lb, but he must pull 2,000 ft of rope through the pulley system. Find the efficiency of the process.

$$\text{Efficiency} = \frac{\text{output}}{\text{input}} = \frac{5 \times 2{,}000\ \text{lb} \times 10\ \text{ft}}{50\ \text{lb} \times 2{,}000\ \text{ft}} = \frac{100{,}000}{120{,}000} = 83\%$$

Power

Power is the rate at which work is being done, or the rate at which energy is being transformed. Mechanical power is expressed as

$$P = \text{work per unit time} = \frac{F \times s}{t}$$

The faster a given amount of work is done, the greater is the power. Raising the 5-ton load in the preceding example a distance of 10 ft in 20 min represents an average output power of

$$P = \frac{5 \times 2{,}000 \text{ lb} \times 10 \text{ ft}}{20 \text{ min}} = \frac{100{,}000 \text{ ft-lb}}{20 \text{ min}} = 5{,}000 \text{ ft-lb/min}$$

Doing the same job in 4 min would represent an output power of 25,000 ft-lb per min.

In order to dramatize the capabilities of his steam engine, Watt studied the work done by horses. He concluded that a horse can do work continuously at the rate of about 33,000 ft-lb per min. An output of 25,000 ft-lb per min is equivalent to 25,000/33,000 = 0.76 horsepower (hp). Since power is work per unit of time, work is power *times* time One horsepower-hour (hp-hr) is the total work done by the "standard horse" in one hour and is equal to 33,000 ft-lb per min × 60 min = 1,980,000 ft-lb. The electrical engineer measures power in watts or kilowatts and work or energy in watt-seconds or kilowatthours (kwhr); 1 horsepower is equal to 0.746 kilowatt. Efficiency can be expressed in terms of power output and input just as well as in terms of energy.

EXAMPLE: The engine of the "hot" stock car is advertised as being capable of developing 250 hp. What actual horsepower is contributing to the acceleration during the performance run?

It was previously determined that 343,000 ft-lb of net work was done on the car in accelerating from 30 to 60 mph in 5 sec. Therefore,

$$P = \frac{343{,}000 \text{ ft-lb}}{5/60 \text{ min}} = 4{,}120{,}000 \text{ ft-lb/min}$$

or

$$P = \frac{4{,}120{,}000}{33{,}000} = 125 \text{ hp}$$

During the performance run, the engine probably developed only about 200 hp, since the 250-hp figure is for top speed. Of that 200 hp, part went to operate various accessories such as fan, water pump, and generator; additional power was lost in the transmission and differential gears. The remainder was available at the rear wheels, but part went to overcoming rolling and air friction. The efficiency of the car in converting developed power into accelerated motion would be expressed as the ratio of 125 to 200, say.

CONCLUSION

Obviously this has been a very brief discussion of just a few of the topics in the important subjects of materials and mechanics. If you are now aware of the type of problems encountered in this field of engineering knowledge, familiar with the technical terminology, and acquainted with some of the basic principles and concepts, then the purpose of this chapter has been accomplished.

ASSIGNMENTS

EXERCISES: Assignments 16-1 to 16-22 are idealized problems to illustrate principles.

16-1. A short wooden 4-by-4 post carries a load of 12,000 lb. Calculate the average stress.

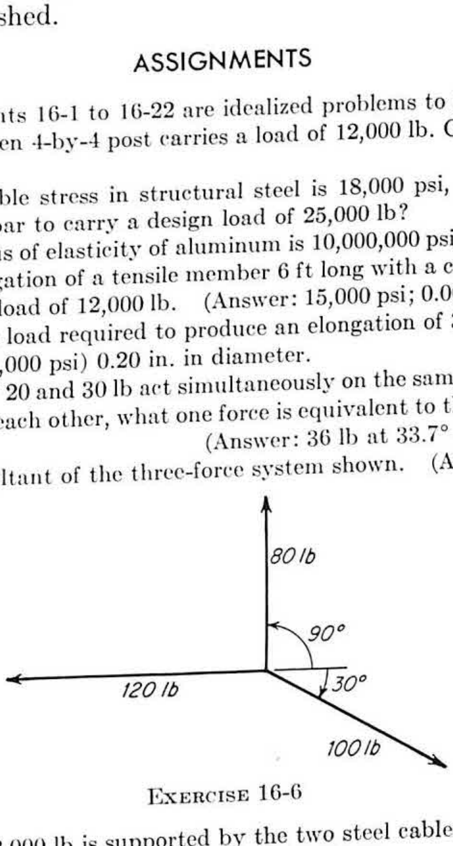
16-2. If the allowable stress in structural steel is 18,000 psi, what should be the diameter of a round bar to carry a design load of 25,000 lb? (Answer: 1.33 in.)

16-3. If the modulus of elasticity of aluminum is 10,000,000 psi, calculate the stress, strain, and total elongation of a tensile member 6 ft long with a cross-sectional area of 0.80 sq in. carrying a load of 12,000 lb. (Answer: 15,000 psi; 0.0015 in./in.; 0.108 in.)

16-4. Calculate the load required to produce an elongation of 3 in. in 100 ft of copper wire ($E = 16,000,000$ psi) 0.20 in. in diameter.

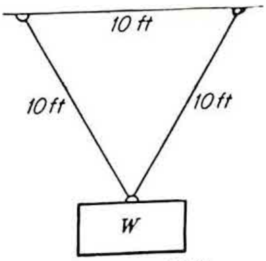
16-5. Two forces of 20 and 30 lb act simultaneously on the same object. If the forces act at right angles to each other, what one force is equivalent to their combined effect? (Answer: 36 lb at 33.7° with the 30-lb force)

16-6. Find the resultant of the three-force system shown. (Answer: 45 lb at 138°)



EXERCISE 16-6

16-7. A weight of 2,000 lb is supported by the two steel cables shown. What is the force in the cable?

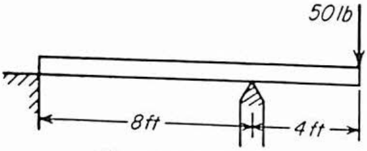


EXERCISE 16-7

16-8. A truck weighing 6,000 lb has a wheel base of 10 ft. The center of gravity of the unloaded truck is located 40 in. behind the front axle. If a load of 5 tons is located symmetrically over the axles, find the magnitude and line of action of the total resultant force.

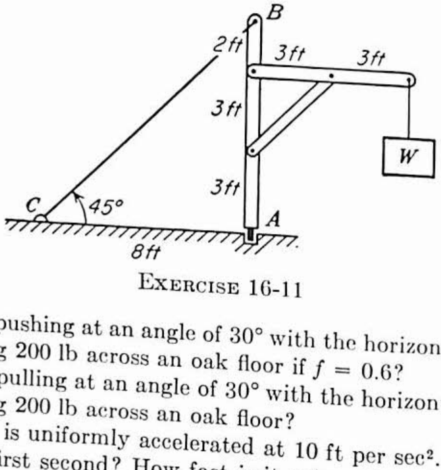
16-9. Find the force on each wheel of the truck in Prob. 16-8.
(Answer: 4,500 lb on each front wheel)

16-10. A 12-ft beam weighing 5 lb per ft is supported as shown. If a load of 50 lb is applied at the end, find the reactions at supports A and B.
(Answer: $R_a = -10$ lb; $R_b = +120$ lb)



EXERCISE 16-10

16-11. If the derrick shown supports a weight of 4,000 lb, find the tension in the cable and the horizontal and vertical components of the forces at the pivot A.



EXERCISE 16-11

16-12. What force pushing at an angle of 30° with the horizontal is required to start a steel trunk weighing 200 lb across an oak floor if $f = 0.6$? (Answer: 212 lb)

16-13. What force pulling at an angle of 30° with the horizontal is required to start a steel trunk weighing 200 lb across an oak floor?

16-14. An airplane is uniformly accelerated at 10 ft per sec². What is the distance traveled during the first second? How fast is it going after 10 sec? How far does it travel in 10 sec?
(Answer: 5 ft, 68 mph, 500 ft)

16-15. If the airplane of Prob. 16-14 has a minimum flying speed of 90 mph, how long a runway is required?

16-16. A bullet from a rifle with a barrel 3 ft long has a muzzle velocity of 2,000 ft per sec. Assuming uniform acceleration, find the time to travel the length of the barrel and the acceleration.

16-17. A baseball is hit straight upward with an initial velocity of 90 ft per sec. Neglecting air friction, calculate the maximum height reached by the ball, its velocity at the end of 2 sec, its height at the end of 3 sec, and the total time it is in the air.

16-18. An airplane weighing 2800 lb is designed to reach a speed of 60 mph in 40 sec. What is the design acceleration, assuming uniform acceleration? Neglecting air and rolling friction, what thrust is required to provide that acceleration? If the plane cruises at 80 mph while developing a thrust of 180 lb, what is the horsepower developed?
(Answer: 2.2 ft/sec², 191 lb, 38.4 hp)

16-19. An airplane weighing 24,000 lb cruises at 192 mph while developing a total of 900 hp at its two propellers. If a maximum of 1,500 hp is available at that speed, what is the maximum rate of climb (increase in vertical height in feet per minute)? (Note: the additional horsepower is available to lift the airplane against gravity.)

16-20. What is the kinetic energy of a 3,600-lb automobile traveling at 30 mph? At 60 mph? At 90 mph? (Answer: 108,000 ft-lb)

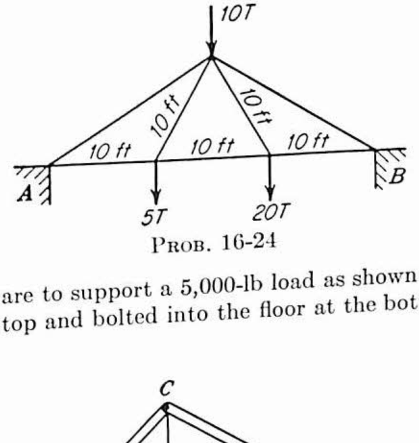
16-21. A single-stage centrifugal water pump has an efficiency of 75 per cent while pumping 500 gpm against a head of 400 ft. The work of the pump consists of raising the weight of the water to the height of the head. What is the required horsepower of the driving motor? (Answer: 67.5 hp)

16-22. The 12,000-hp single-stage single-suction pumps for the Colorado River Aqueduct pump 200 cu ft per sec of water against a head of 444 ft (see Exercise 16-21). What is the efficiency? What are the losses?

PROBLEMS: Assignments 16-23 to 16-26 are mechanical engineering problems to be solved by the complete five-step approach outline in Chap. 15. Your instructor will discuss with you the simplifying assumptions which can be made. Wherever applicable, make use of the free-body diagram showing the forces acting on some portion of the structure.

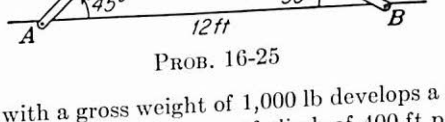
16-23. To pull a stalled automobile out of the mud, a man ties one end of a 50-ft cable to the front of the car and the other end to a tree. If in standing on the center of the taut cable he depresses it 2 ft, what pull is exerted on the car?

16-24. A steel truss is supported by columns A and B and loaded as shown. What are the forces on the columns?



PROB. 16-24

16-25. Two timbers are to support a 5,000-lb load as shown. The timbers are to be bolted together at the top and bolted into the floor at the bottom. What size timbers should be used?



PROB. 16-25

16-26. A Piper Cub with a gross weight of 1,000 lb develops a total power of 40 hp; it has a cruising speed of 72 mph and a rate of climb of 400 ft per min. A similar but larger plane is to be designed for a gross weight of 2,000 lb and a rate of climb of 800 ft per min. Approximately what horsepower should be provided?

17

PREVIEW OF THERMODYNAMICS

A recent issue of *The Machinist*, publication of the International Association of Machinists, describes a new type of automobile carburetor which will, in the words of the inventor, "give 100 to 400 miles per gallon." A question frequently put to engineers is: "Isn't it true that improved carburetors have been invented which will give over 100 miles per gallon and that oil companies have bought the patents and are keeping the carburetors off the market in order to keep gasoline sales up?"

Evaluating the inventor's claim and answering the question require some knowledge of automotive engine operation and an understanding of the underlying thermodynamic principles. Thermodynamics means, literally, the science of "heat power," and it is concerned with generating and controlling energy in the form of heat and transforming it into other useful forms. Thermodynamic devices include steam power plants, steam and gas turbines, automotive and diesel engines, refrigerating units, and air-conditioning systems. Sometimes there is a distinction between the "science" of thermodynamics and the "art" of heat-power engineering.

This brief preview of thermodynamics serves as an introduction to an important field of engineering. Heat is considered as a form of energy, and various methods of heat transfer are described. The underlying physical principles are discussed and then applied, in simplified form, to the steam power plant, the automotive engine, and the home refrigerator. The emphasis is on the quantitative approach characteristic of engineering.

HEAT AS A FORM OF ENERGY

The primary source of energy on the earth is the sun. The sun's radiant energy streams out in all directions. A minute fraction strikes the earth and is utilized by plants and animals; is stored in the form of coal, wood, and petroleum; or is converted to the energy of falling water or moving wind. We are well aware of the sun's energy on a hot summer day and of its absence on a cold winter night.

Temperature

The intensity or level of heat energy is called *temperature*. A tub of lukewarm water may contain the same amount of heat energy as a teakettle of boiling water, but the heat intensities, and therefore the temperatures, are different.

Temperatures are relative and are measured in *degrees* on a scale by means of thermometers. So that a temperature of 75° on a given scale will mean the same the world over, thermometers are calibrated under conditions which can be duplicated in any laboratory. The common references are the melting point of ice and the boiling point of water.

States of Matter

While there are only 92 different natural atoms, there are thousands of thousands of different substances. The smallest part of a substance which behaves as a unit particle is a molecule. Monatomic molecules such as helium (He) and neon (Ne) contain only a single atom; diatomic molecules such as oxygen (O_2) and carbon monoxide (CO) contain two atoms. Molecules can contain almost any number of atoms; those containing three or more atoms–for example, water (H_2O) and octane (C_8H_{18})–are called polyatomic.

A substance may exist in the *solid state*, the *liquid state*, or the *gaseous state*. The different behavior of a substance in the various states is explained in terms of the energy of its molecules. This molecular energy is called *internal energy*, and its intensity is measured by the temperature of the substance. Substances are changed from one state to another by the addition or removal of heat.

Changes in State

Suppose that a 1-lb block of ice is placed in a pan over a fire. The atoms of hydrogen and oxygen making up the ice are held rather rigidly with respect to adjacent atoms. While these rigid bonds are characteristic of the solid state, the atoms and molecules do possess kinetic energy in the form of vibrations, and it is this kinetic energy, low in ice, which is called internal energy.

As the pan becomes warm, its atoms and molecules receive additional heat which takes the form of increased vibration. The surface of the pan is in contact with the ice, and the increased activity is imparted to the adjacent ice particles and transmitted throughout the block of ice. In this way the ice is warmed, and its temperature rises.

This process continues with the addition of more heat energy until a point is reached where no more kinetic energy can be absorbed under the restricted conditions of the solid state. Individual molecules absorb so much energy that they break away from the solid state and move rapidly about. The ice begins to melt.

With the continued addition of heat, more and more of the ice is changed to water. The temperature of the ice and water remains constant because the added energy is going to the transformation of the substance from one state to a higher energy state. When all the ice is melted, the addition of more heat causes the temperature of the liquid to rise as the kinetic energy of the molecules increases.

The temperature continues to rise as heat is added until the boiling point is reached. At this temperature, liquid molecules possess a maximum of kinetic energy, and absorbing additional energy permits them to change from the closely packed liquid state to the high-energy, rarefied gaseous state. Again the temperature of the water (and of the steam also if the pan is covered) remains constant until sufficient heat has been added to convert all the liquid to vapor. With additional heat the temperature of the steam will rise higher and higher.

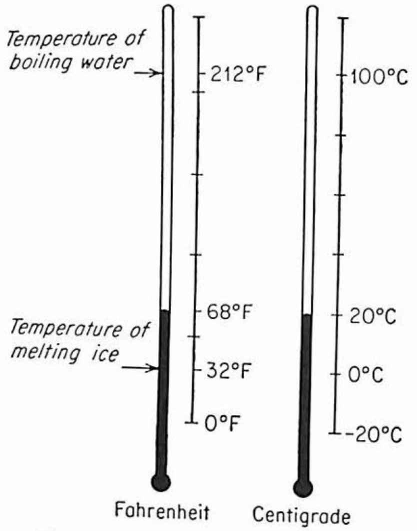


FIG. 17-1. Temperature scales.

Units of Temperature and Heat

On the Fahrenheit scale used in engineering, the melting point of water is designated as 32° and the boiling point at atmospheric pressure is marked 212°. On the centigrade scale used by scientists, the corresponding points are 0 and 100°. As 100° along the centigrade scale is equivalent to $212° - 32°$, or 180°, along the Fahrenheit scale, 1°C is equivalent to $\frac{9}{5}$°F. To convert from degrees centigrade to degrees Fahrenheit, multiply by $\frac{9}{5}$ and add 32.

The engineering unit of heat is the *British thermal unit* (Btu), which is equal to the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit. Scientists use the *calorie*, which is the amount of heat required to raise the temperature of one gram of water one degree centigrade. The heat required to raise the temperature of one pound of any substance one degree Fahrenheit is called its *specific heat*. The specific heat of water is 1.0; of iron, 0.105; of ice, 0.504.

Figure 17-2 shows the temperature-heat relationship during the heating of 1 lb of ice at −50°F to 1 lb of steam. The 144 Btu required to convert 1 lb of ice at 32°F to 1 lb of water at 32°F is called the *heat of fusion*. The 970 Btu required to convert 1 lb of water at 212°F to 1 lb of steam at 212°F is called the *heat of vaporization*. Water is used in many thermodynamic processes because, not only is it cheap, but these high heats of fusion and vaporization are desired properties. Note that if steam is condensed, it gives up 970 Btu per lb and if water is frozen, it gives up 144 Btu per lb.

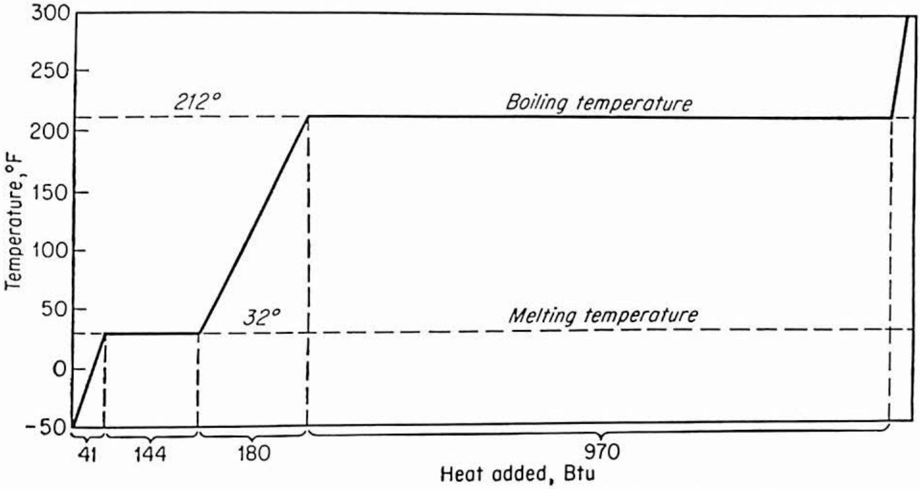


FIG. 17-2. Heat of fusion and heat of vaporization of water.

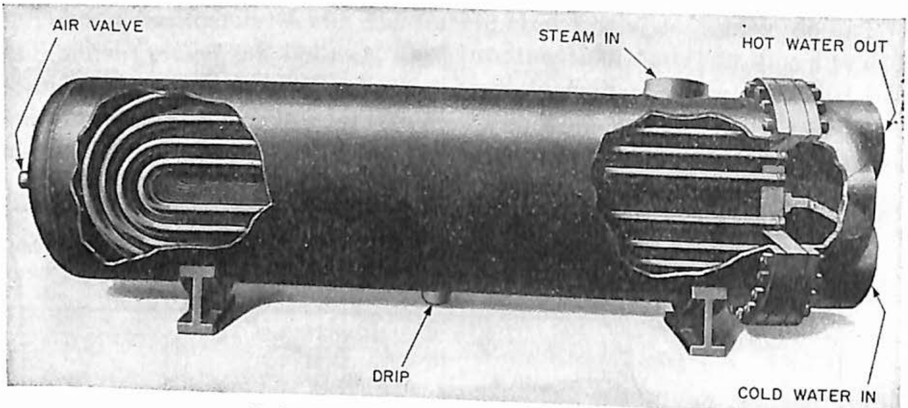
HEAT TRANSFER

In equipment using heat energy it is usually necessary to transfer heat from one place to another or from one body to another. All the various methods of heat transfer depend upon *conduction*, *convection*, *radiation*, or a combination of these basic processes.

Conduction

When heat is transferred through a substance by induced molecular activity, the process is called *conduction*. This is a relatively slow process and is usually limited to thin partitions of relatively high *thermal* conductivity, as through the bottom of a cooking pan or through the walls of a boiler tube. Copper and silver are excellent conductors of heat, and most other metals are good, but wood, paper, and still air and water are poor conductors. A poor conductor which has other desirable properties may be used as an *insulator* to prevent heat conduction.

It can be demonstrated experimentally that the amount of heat conducted through a body per unit of time is directly proportional to the



Industrial Heat-exchanger Construction

The heating steam enters at the top and, in condensing around the cooler pipes, gives up its heat of vaporization. The condensate flows out at the bottom. In this "two-pass" heater, the cool water enters at the bottom and flows through the "tube bundle" to the other end and back again. The U design permits each tube to expand and contract independently. The capacity of the unit depends primarily on the tube surface area available for heat transfer. (*Patterson-Kelley Co.*)

conductivity of the material, to the cross-sectional area through which the heat flows, and to the difference in temperature between the ends; it is inversely proportional to the length of the heat path. Expressed mathematically,

$$Q = \frac{kA(T_b - T_a)}{L}$$

where Q = heat conducted, Btu per hr
k = thermal conductivity, Btu per hr per sq ft per °F per ft
A = cross-sectional area, sq ft
$T_b - T_a$ = temperature difference, °F
L = length of path, ft

Typical values of k are as follows:

Material	k	Material	k	Material	k
Copper	220	Water	0.35	Air	0.013
Silver	240	Concrete	0.6	Kapok	0.020
Iron	38	White fir	0.06	Rock wool	0.023

EXAMPLE: Calculate the temperature drop across a copper plate 1 in. (0.0833 ft) thick when the heat flow is 50 Btu per hr per sq ft.

$$T_b - T_a = \frac{Q}{A}\frac{L}{k} = 50\,\frac{0.0833}{220} = 0.019°\text{F}$$

EXAMPLE: Repeat the above example for 1 in. of rock wool.

$$T_b - T_a = 50\,\frac{0.0833}{0.023} = 181°\text{F}$$

Convection

Although water is a relatively poor conductor, it is widely used in heat-transfer equipment. When peas are cooked in a pan on a stove, the water in contact with the bottom of the pan is heated quickly by conduction. In being heated it expands, becomes less dense than the cold water above, and therefore rises to the top. The heat from the bottom of the pan is quickly carried to the peas at the top. The process of carrying heat from one place to another within a fluid by movement of the fluid itself is called *convection*. When the fluid moves as a result of differences in density, the process is called *free convection;* when the fluid is made to flow by a fan or pump, it is called *forced convection*.

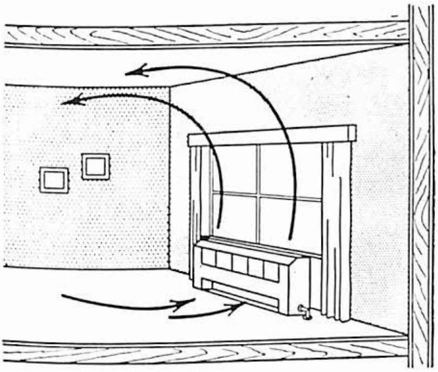


FIG. 17-3*a*. Free convection.

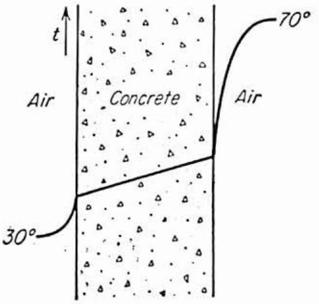


FIG. 17-3*b*. Temperature drops.

Forced convection is used in cooling engine cylinders, in radiator tubes, in boilers, and in condensers. The common situation is where heat is transmitted from one fluid to another through a separating metal wall. The high conductivity of the metal offers little resistance to the flow of heat, and within the fluids heat transfer by mixing occurs rapidly. Right next to the wall, however, there is a stagnant film of liquid which offers practically all the thermal resistance and across which a high temperature difference is required. The effect of this film, of indefinite thickness, is considered as a "film coefficient," which is used in the conductivity formula in place of k/L. The film coefficient is dependent upon such factors as conductivity, viscosity, density, and velocity of the fluid and the shape and arrangement of the heating surface. A great deal of research and experimentation has been and is being performed to provide film coefficient values for design engineers.

EXAMPLE: In designing heating systems it is customary to use film coefficients $f_i = 1.65$ and $f_o = 6.0$ for the inside and outside surfaces of building walls. These values assume free convection currents on the inside and a 15-mph wind on the outside.

For a 70° inside temperature and 30° outside temperature, find the heat loss per square feet through a 6-in. (0.5-ft) concrete wall.

Across the outside film: $T_b - T_a = \frac{Q}{A} \frac{1}{f_o}$

Across the concrete: $T_c - T_b = \frac{Q}{A} \frac{k}{L}$

Across the inside film: $T_d - T_c = \frac{Q}{A} \frac{1}{f_i}$

Since the total temperature drop is the sum of the three and Q/A is the same through all sections,

$$T_d - T_a = \frac{Q}{A}\left(\frac{1}{f_o} + \frac{k}{L} + \frac{1}{f_i}\right)$$

or

$$\frac{Q}{A} = \frac{T_d - T_a}{1/f_o + k/L + 1/f_i} = \frac{70 - 30}{1/1.65 + 0.6/0.5 + 1/6.0} = 20 \text{ Btu/hr-sq ft}$$

Radiation

Every heated body loses heat continuously by *radiation*. Radiation is the process whereby the sun transmits its heat across space to the earth. Heat waves, or infrared waves, are light waves of a little longer wavelength which makes them invisible to the human eye. The pleasant warmth of a fireplace is due to radiated heat which travels with the speed of light and is blocked by any solid object. The convection currents set up by the fire actually remove warm air from the room along with the smoke, and as a result, a fireplace is an inefficient heater which must be justified by the pleasure derived from the accompanying light and sound and the fact that we prefer the sensation of receiving heat by radiation rather than by convection.

The radiation of energy is due to the intense activity of the atoms in the heated body. This activity is dependent upon the temperature of the body, and even the atoms in a block of ice possess internal energy of motion. As a body is cooled, the internal energy decreases until finally, at −460°F, the internal energy and therefore the radiation become zero. Because of this and another experimental fact discussed on page 288, the temperature −460°F is called absolute zero. The Rankine temperature scale (named after Glasgow University professor William J. M. Rankine) is referred to this zero, and therefore 70°F, for example, would be $70 + 460 = 530$°R or 530° absolute.

The heat radiated by a body depends on its area, surface condition, and absolute temperature. The heat received from surrounding bodies or surfaces depends on the same factors. Since all bodies are radiating and receiving energy continuously, the hot bodies tend to cool and the cool bodies tend to become warmer. A person with a skin temperature of 85°F sitting in a room with an air temperature of 72° and an average wall temperature of 68° feels quite comfortable because his net losses by radiation, convection, and evaporation are made up by normal body functioning. Sitting in front of a large glass area at a temperature of 45° will cause discomfort because the losses by radiation are excessive even though the room air temperature stays at 72°.

THE GAS LAWS

A steam power plant is a cyclic operation in that the water is heated to steam in a boiler, pumped to the turbine, expanded in the turbine to perform useful work, condensed in the condenser, and then pumped back to the boiler. Practically all heat power systems involving work and heat operate on some type of *thermodynamic cycle*. In the case of the steam power plant, the *working fluid* is steam. In other systems the working fluid may be air, another gas, or a mixture of air and gases. In order to apply gases to practical purposes, the engineer must understand the relationships between the temperature, pressure, and volume of a gas.

Boyle's Law

In 1660 Robert Boyle discovered that if the temperature remains constant, the volume of any gas varies inversely as the pressure. In other words, if the pressure is doubled, the volume is reduced to half. This relationship can be expressed mathematically by

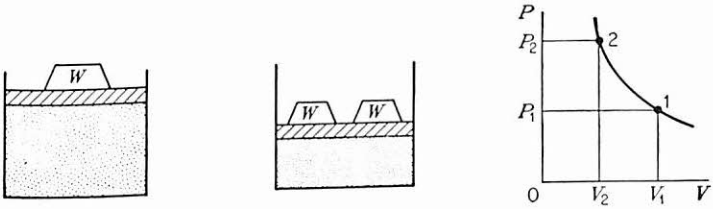


FIG. 17-4. Boyle's law.

$$\frac{P_2}{P_1} = \frac{V_1}{V_2} \qquad \text{or} \qquad P_2V_2 = P_1V_1 = \text{constant}$$

where P and V are the pressure and volume under conditions 1 and 2. As indicated in the sketch, if a given volume of gas is held under pressure by a weight W on the piston, doubling the pressure reduces the volume to half. The relationship can be shown on a graph as indicated.

Charles's Law

Over one hundred years later Jacques Charles observed that if the pressure is held constant, the volume of any gas varies linearly with temperature. The relationship is indicated in the graph and can be expressed mathematically as

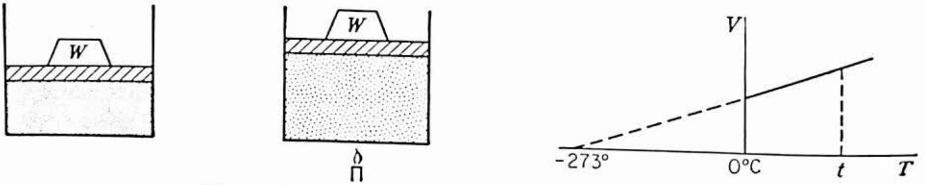


FIG. 17-5. Charles's law with constant pressure.

$$V_t = V_0(1 + Bt)$$

The quantity B is the *coefficient of expansion* and, as Charles discovered, is equal to approximately $1/273$ for all gases. In other words, if the graph were extended, zero volume would occur at $-273°C$.

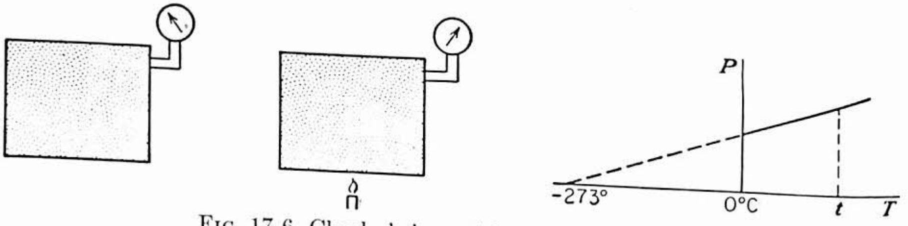


FIG. 17-6. Charles's law with constant volume.

If the volume is kept constant, Charles noted that the variation of pressure with temperature is a straight line following the equation

$$P_t = P_0(1 + Bt)$$

Again B has a value of approximately $1/273$ for all gases, indicating that pressure is zero at $-273°C$. But according to the accepted theory of gases, pressure on the walls of a container represents the average effect of the bombardment by a host of tiny molecules in motion. Because this energy of motion is what is called internal energy and is measured by temperature, it was concluded that the absolute zero of temperature must correspond to the indicated zero of pressure. Therefore, $-273°C$ or its equivalent, $-460°F$, is used as a reference temperature in thermodynamic calculations.

Using absolute temperature T, Charles's laws can be rewritten as

$$\frac{P_2}{P_1} = \frac{T_2}{T_1} \quad \text{or} \quad \frac{P_2}{T_2} = \frac{P_1}{T_1} = \text{constant}$$

and

$$\frac{V_2}{V_1} = \frac{T_2}{T_1} \quad \text{or} \quad \frac{V_2}{T_2} = \frac{V_1}{T_1} = \text{constant}$$

where P, V, and T are the pressure, volume, and temperature under conditions 1 and 2.

Combining Boyle's law and Charles's laws yields a general gas law which states that

$$\frac{P_2V_2}{T_2} = \frac{P_1V_1}{T_1} = \text{constant}$$

Many gases of engineering importance such as air, oxygen, and nitrogen follow these laws very closely in the usual ranges of temperature and pressure. The laws do *not* hold for vapors such as steam in a turbine or ammonia in a refrigeration machine; special tables of data are available for calculations involving vapors.

Absolute and Gage Pressure

We live at the bottom of a "sea" of air called the atmosphere. As a result of the weight of the air, it exerts a pressure at sea level of approximately 14.7 psi. The air pressure varies inversely with height above sea level and changes slightly with changing weather conditions. The common pressure gage measures the difference between the pressure in a tire, say, and the atmospheric pressure; if the tire gage reads 30 psig (gage), the actual or absolute pressure is 30 + 14.7 = 44.7 psia (absolute). The gas laws are based on variations in absolute pressure.

EXAMPLE: One cubic foot of hydrogen at atmospheric pressure is compressed to a volume of 0.2 cu ft. Assuming constant temperature, find the pressure.

From Boyle's law, $P_2V_2 = P_1V_1$

or

$$P_2 = P_1\frac{V_1}{V_2} = 14.7 \times \frac{1}{0.2} = 73.5 \text{ psia}$$

or

$$P_2 = 73.5 - 14.7 = 58.8 \text{ psig}$$

EXAMPLE: One cubic foot of air at atmospheric pressure and 60°F is sealed in a container. If the air is heated to a temperature of 190°F, find the resulting pressure.

Since the volume is constant, by Charles's law

$$\frac{P_2}{P_1} = \frac{T_2}{T_1} \qquad \text{or} \qquad P_2 = P_1 \frac{T_2}{T_1}$$

$$P_2 = 14.7 \times \frac{460 + 190}{460 + 60} = 18.4 \text{ psia}$$

or

$$P_2 = 18.4 - 14.7 = 3.7 \text{ psig}$$

EXAMPLE: In a certain process 0.30 cu ft of a gas initially at 120°F and 10 psig is heated to 640°F and subjected to a pressure of 250 psig. Find the new volume.

From the general gas law,

$$\frac{P_2V_2}{T_2} = \frac{P_1V_1}{T_1}$$

or

$$V_2 = V_1 \frac{P_1}{P_2} \times \frac{T_2}{T_1} = 0.30 \times \frac{14.7 + 10}{14.7 + 250} \times \frac{460 + 640}{460 + 120} = 0.053 \text{ cu ft}$$

Work Done in Expansion

It is hard work to inflate a tire using a hand pump. What work is being done in an engineering sense? As indicated in the sketch, the position of the piston of the pump corresponds to the volume of air. After the pump is pushed to the extreme left, zero volume (point 1), it is pulled to the right, sucking in air at atmospheric pressure P_1. After the piston reaches the extreme right (point 2) and starts back, the valves on the piston close. The trapped air is then compressed as the piston moves back to point 3. If pressure P_3 is equal to the pressure in the tire, the tire valve opens and the high-pressure air is forced in.

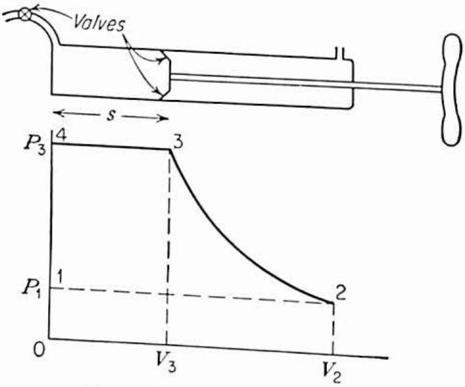


FIG. 17-7. Air compression.

The force necessary on the piston during the process 3 to 4 is the pressure P_3 times the area A of the piston. The distance moved is s, which equals V_3/A. Since work is force times distance,

$$W_{3-4} = F \times s = P_3 A \times \frac{V_3}{A} = P_3 V_3$$

Since the space above the piston is at atmospheric pressure, the force necessary on the handle is $(P_3 - P_1)A$. Therefore the work done by the pumper during this part of the cycle is

$$W_{3-4} = (P_3 - P_1)V_3$$

If the tire pressure is 30 psi as measured by a gage, the actual pressure is 30 + 14.7, or 44.7 psi, since the gage reads the excess in pressure over atmospheric pressure. If the valve opens when the remaining pump volume is 6 cu in., the work done in the remainder of the stroke is

$$W_{3-4} = (P_3 - P_1)V_3 = (44.7 - 14.7)6 = 180 \text{ in.-lb} = 15 \text{ ft-lb}$$

The total work done includes the work done in compressing the air from V_2 to V_3, but during this process the pressure is varying continuously and the evaluation of pressure × volume to obtain work is complicated. One approach is to consider the pressure change to occur in a series of steps and calculate the total work by adding up the work of all the steps. The method of calculus gives an exact answer by integrating an infinite number of infinitesimal steps.

THE STEAM POWER PLANT

The steam power plant is an example of a thermodynamic cycle in which heat is added to and work extracted from the working fluid as it circulates through the various components. As the fuel burns, water is converted to high-energy, high-pressure steam in the boiler or steam generator and sent to the turbine. As the steam expands, part of its internal energy is converted into kinetic energy which is utilized by the turbine in driving the electric generator. The exhaust steam is drawn into

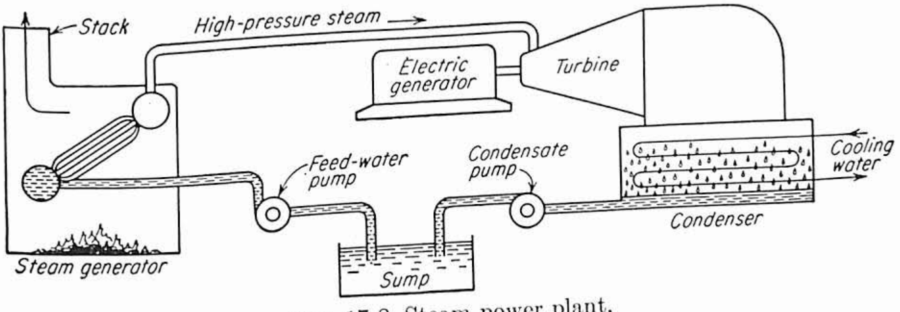


Fig. 17-8. Steam power plant.

the condenser and condensed by the cooling water, creating a partial vacuum and thereby increasing the efficiency of the turbine. The condensed steam is pumped out by the condensate pump and into a reservoir at atmospheric pressure. The feed water is then pumped into the boiler at high pressure, and the cycle is complete.

Applying the law of conservation of energy (referred to as the *first law of thermodynamics*) to this cycle,

$$\text{Energy in} = \text{energy out}$$

or heat added + work input = heat rejected + heat lost + work output or

$$Q_a + W_{\text{in}} = Q_r + Q_l + W_{\text{out}}$$

where Q_a = heat added in the boiler
Q_r = heat rejected to condenser cooling water
Q_l = heat lost by conduction, convection, and radiation
W_{in} = work done on the fluid by the pumps
W_{out} = useful work developed in the turbine

In most modern installations, W_{in} and Q_l are negligibly small compared with the other quantities; therefore

$$W = Q_a - Q_r$$

EXAMPLE: In a certain steam plant 10,000 lb of steam is circulated each hour. If 1200 Btu per lb is supplied in the boiler and 900 Btu per lb is carried away in the condenser, calculate the output and the thermal efficiency.

$$W = Q_a - Q_r = 1200 - 900 = 300 \text{ Btu per lb of steam}$$

$$e = \frac{\text{output}}{\text{input}} = \frac{\text{useful work done}}{\text{heat energy added}} = \frac{300}{1200} = 25\%$$

The work per hour will be 10,000 × 300 = 3,000,000 Btu per hr. To convert these heat units to horsepower, we note that 1 Btu = 778 ft-lb as determined experimentally and 1 hp = 33,000 ft-lb per min by definition. Then

$$1 \text{ hp} = \frac{33{,}000}{778} = 42.42 \text{ Btu/min or } 2545 \text{ Btu/hr}$$

$$3{,}000{,}000 \text{ Btu/hr} = \frac{3{,}000{,}000}{2545} = 1{,}180 \text{ hp}$$

THE LAWS OF THERMODYNAMICS

The science of thermodynamics is based on a few fundamental laws. Boyle's law and Charles's law have been stated and applied. There are three fundamental principles which justify further discussion.

The First Law

The principle that energy may be converted from one form to another but neither created nor destroyed finds application in many engineering fields. Recent advances in physics have made it necessary to include matter as a form of energy, but the truth of the fundamental concept still stands. The principle takes on a variety of forms as it is used to solve problems in mechanics, hydraulics, electric circuits, and thermodynamics.

One application in thermodynamics is in connection with what the engineer calls a *heat balance*. This is a detailed expression of the fact that energy in equals energy out. In a diesel engine, for example, the energy input (Q_a) is in the form of a fuel with a certain *heating value*, approximately 20,000 Btu per lb. In addition to useful work output (W), work will be required to drive the accessories (W_{acc}), work will be lost in mechanical friction (W_f), and energy will be transferred to the cylinder cooling water (Q_{cw}) and to the lubricating oil (Q_{lo}), lost from the surface of the engine (Q_{sur}), and carried away in the exhaust (Q_{ex}). The heat balance considering these factors would be

$$Q_a = W + W_{acc} + W_f + Q_{cw} + Q_{lo} + Q_{sur} + Q_{ex}$$

Similar heat balances are useful in analyzing the performance of all types of heat-power devices.

The Second Law

Some of the energy carried away in the exhaust of a diesel engine is due to the fact that combustion is not complete; however, the largest part of the exhaust energy is *rejected heat*. In the simplified example of the steam cycle, 75 per cent of the input heat was rejected in the condenser. Why is some heat always rejected? Why can't it all be used?

Consider a hydroelectric plant in which the energy of the water is directly proportional to the height through which it falls in going from behind the dam to the water turbine. The potential energy of position is changed to kinetic energy in the stream which turns the turbine. But after the water leaves the turbine and flows downstream, it still has potential energy. This energy could be utilized by digging a deep hole and placing the turbine at the bottom. What is wrong with this scheme? Of course, the used water would have to be pumped out of the hole, and the energy required would be greater than the additional amount obtained from the turbine. The spent water must always be removed, and since water flows freely downhill only, the water must be discharged at the lowest point where it will flow away naturally.

So it is with heat energy, which is measured above absolute zero. The working fluid must reject heat to the best natural receiver, and that will be some low-temperature body such as a lake, a stream, the ocean, or the atmosphere. Energy which exists at a low temperature is said to be *unavailable.* For example, a forest stream carrying 2,000 cu ft per sec of water at 50°F and weighing 62.5 lb per cu ft represents, with respect to 32°F,

$$2{,}000 \times 62.5 \times (50 - 32) = 2{,}250{,}000 \text{ Btu per sec}$$

or over 3 million hp! But, alas, this power is unavailable because heat energy can flow only from a high temperature to a lower temperature and there is no large receiver of energy which can be maintained economically at freezing temperature. An even larger amount of energy is unavailable because there is no receiver at zero temperature absolute.

The second law of thermodynamics says that no device, actual or ideal, can both continuously and completely convert heat into work; some of the heat must be rejected.

Carnot Efficiency

When the mechanical engineer designs a steam plant with an over-all efficiency of 20 per cent and the hydraulic engineer designs a hydro plant with an over-all efficiency of 80 per cent, does that mean that the art of mechanical engineering is far behind that of hydraulics? No, it merely means that in calculating thermal efficiency, the heat-power plant is charged with energy which everyone concedes is unavailable. Then how can we evaluate the work of an engine designer?

Over a hundred years ago, a young Frenchman named Sadi Carnot demonstrated that since the flow of heat from one body to another is governed by the relative temperatures and since the work done in any process depends on this heat flow, the maximum conceivable thermal efficiency of any cycle is

$$e = \frac{T_1 - T_2}{T_1}$$

where T_1 = highest temperature in the cycle, °R
T_2 = lowest naturally available temperature, °R

EXAMPLE: In the previous steam plant example, the thermal efficiency was calculated to be 25 per cent. If the steam was received at 360°F and the condenser cooling water was 50°F, the maximum theoretical efficiency would be

$$e = \frac{T_1 - T_2}{T_1} = \frac{(360 + 460) - (50 + 460)}{360 + 460} = \frac{310}{820} = 38\%$$

The difference between the theoretical 38 per cent and the actual 25 per cent is primarily due to the compromises which must be made in designing a plant which will be economical to construct and operate.

INTERNAL-COMBUSTION ENGINES

The steam-power-plant cycle requires a series of components with heat added in one, work extracted in another, heat rejected in another, and pumping done by still another. In internal-combustion engines, all these processes take place in the engine itself.

In the four-stroke cycle employed in automotive engines, the intake valve opens near the beginning of the suction stroke and the combustible mixture is drawn into the cylinder. During the compression stroke, the piston compresses the charge to a fraction of its original volume. Near the top of the compression stroke, the fuel is ignited by a spark and burns, rapidly raising the temperature and pressure inside the cylinder. As the burning gases expand, the piston is driven down and power is transmitted to the crankshaft. Near the end of the power stroke the exhaust valve opens, and during the exhaust stroke the burned gases are pushed out.

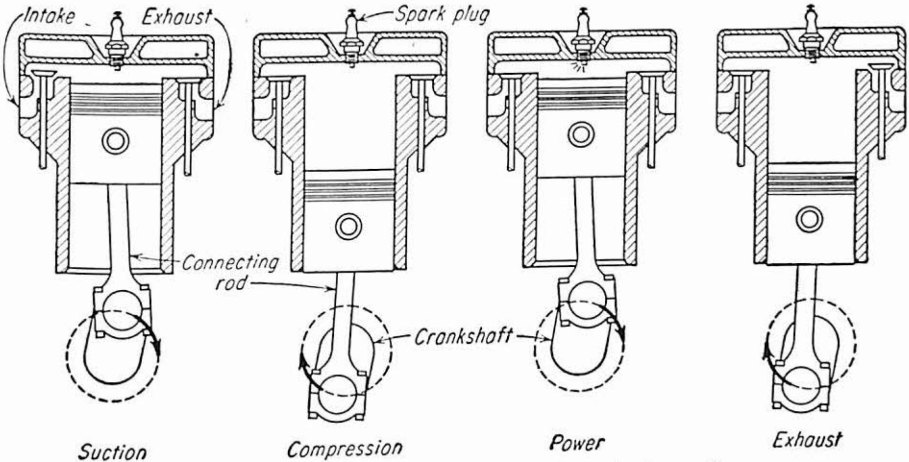


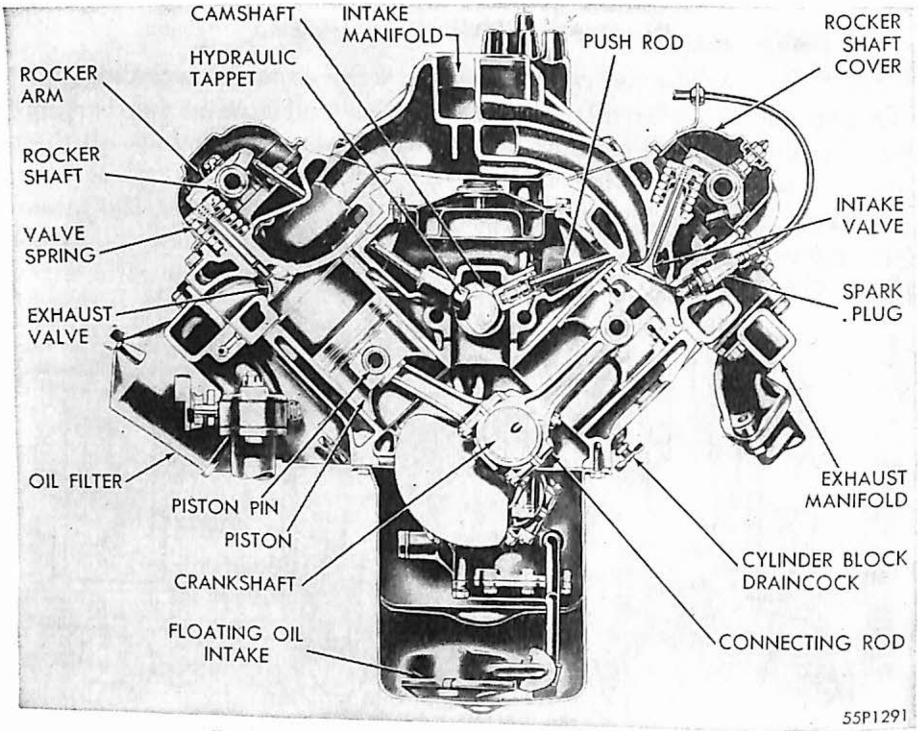
FIG. 17-9. Automotive-type engine, four-stroke cycle.

In this type of engine, the working fluid is a mixture of fuel and air. Heat is added when the fuel burns. Work is done when the hot gases expand and drive the piston down. Heat is rejected to the atmosphere in the form of hot exhaust gases. The closing link in the cycle is the atmosphere, which receives the exhaust gases and supplies the intake air.

The power output of an engine can be determined on a dynamometer, which measures torque and speed. The torque and speed readings can be converted to horsepower by use of the formula

$$\text{Hp} = \frac{2\pi NT}{33{,}000}$$

where N = speed, rpm
T = torque, lb-ft



Section View of V-type Automobile Engine

The combustible mixture of gasoline vapor and air leaves the carburetor (not shown) and enters the *intake manifold* at the top for distribution to each cylinder. As the *camshaft* rotates, lobes or cams operate through tappets, *push rods*, and *rocker arms* to open the *intake* and *exhaust valves* held closed by *valve springs*. The *spark plug* on the right has just fired and the *piston* will be driven down transmitting power through the *connecting rod* to the *crankshaft*. The crankshaft is connected by means of the transmission and the rear axle gearing to the rear wheels. (*Chrysler Corporation.*)

The power of a proposed engine can be predicted from an analysis of the pressure-volume diagram expected. For an *ideal* internal-combustion engine which has no friction or heat losses, the performance can be analyzed mathematically. The efficiency can be shown* to be

$$e = 1 - \frac{1}{r^{k-1}}$$

where r = compression ratio

k = a property of the fuel-air mixture usually taken as about 1.3

Although this equation holds only for ideal engines, the factors which improve the performance of ideal engines will have the same effect in practical engines. In 1948, the average compression ratio of American cars was about 6.5. By 1955, compression ratios of 8.0 were common. The corresponding ideal efficiencies are 43 and 46.5 per cent, respectively.

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* Virgil M. Faires, "Applied Thermodynamics," The Macmillan Company, New York, 1948.

Why weren't compression ratios of 8.0 used before, and why aren't ratios of 10 or 12 used now? The answer is that fuel requirements are more strict in higher compression engines. If the fuel burns too quickly, there is a "detonation" and an audible "ping" rather than a smooth, power-producing burning. Ping, or "knock," can be reduced by proper design of the space above the piston, by minimizing carbon deposits in the cylinder, or by using a gasoline with a higher "octane rating." Octane is a fuel with excellent antiknock properties; other fuels are compared with octane as a standard. As cylinder design improves and better fuels become available, the compression ratio and engine efficiency climb. Unfortunately the increase in efficiency is more than offset by the increased manufacturing cost of high-octane gasoline and by the increased use of auxiliaries such as air conditioning, power steering, and power brakes which take power from the engine.

The Carburetor Patent Legend

Actually the cost of fuel is a relatively small part of the cost of owning an automobile for the average driver; depreciation is the major factor. However, every car owner is interested in the fuel economy of his car, and manufacturers of economical cars boast of the miles per gallon which can be obtained with their products.

The story is heard frequently of a new carburetor which provides the perfect mixture of gasoline and air and thereby yields five or six times as many miles per gallon. Usually the carburetor has been invented by a humble mechanic who has one on his own car but who has been "bought out by the big interests" to keep the improvement off the market. The thermodynamics background of this chapter will permit us to evaluate the possibility of such an improvement.

For any thermodynamic cycle employing heat supplied at temperature T_1 and exhausted at T_2, Carnot demonstrated that there is a maximum conceivable thermal efficiency. In an engine with a peak temperature of 5000°F and exhausting to an atmosphere at 70°F, this maximum conceivable efficiency would be close to 90 per cent. In any kind of useful gasoline engine, however, the theoretical efficiency for an ideal piston-type engine was found to be 46.5 per cent at a compression ratio of 8.0.

A modern engine will allow fuel consumption as low as 0.5 lb per hp-hr. Since motor gasoline has a heating value of about 21,000 Btu per lb and 1 hp-hr is equal to 2545 Btu, the actual efficiency is

$$e = \frac{\text{output}}{\text{input}} = \frac{\text{work done}}{\text{heat added}} = \frac{2545}{0.5 \times 21{,}000} = 24\%$$

Therefore the engine is attaining 24/46.5 = 52 per cent of *perfection*. If an engine of this type provides 18 miles per gal in a given automobile in average driving, the perfect theoretical engine with no losses of any kind would provide 18/0.52 = 35 miles per gal. This is the absolute limit for an engine of this type operating under these conditions in the given automobile. Of this difference between actual and ideal, imperfect carburetion plays only a minor part. Our conclusion is that no carburetor can be expected to double the gasoline mileage of a given engine.

It is possible to get 50 to 60 miles per gal from present automobile engines by taking the following steps:

1. Put the engine in ideal mechanical condition.
2. Use very low viscosity lubricating oil throughout.
3. Disconnect the generator, fan, and water pump.
4. Use narrow tires inflated to extremely high pressure.
5. Reduce weight by removing the body.
6. Drive at a constant speed of 30 mph.

Of course the ride will be unpleasant and the engine won't last long, but the gasoline mileage will be increased.

REFRIGERATION

To make ice, to cool a theater, or to freeze food requires cooling, the transfer of heat in the opposite direction from heating. A common engineering problem involves transferring heat from a low to a high temperature by means of a *heat pump* or *refrigeration machine*. Whereas the steam engine and the internal-combustion engine produce work from heat input, the desired result of the refrigerator is cooling (removal of heat) and the input is work. There are several different forms of practical refrigeration machines, but a discussion of the common household refrigerator will illustrate the fundamental principles of operation of most units.

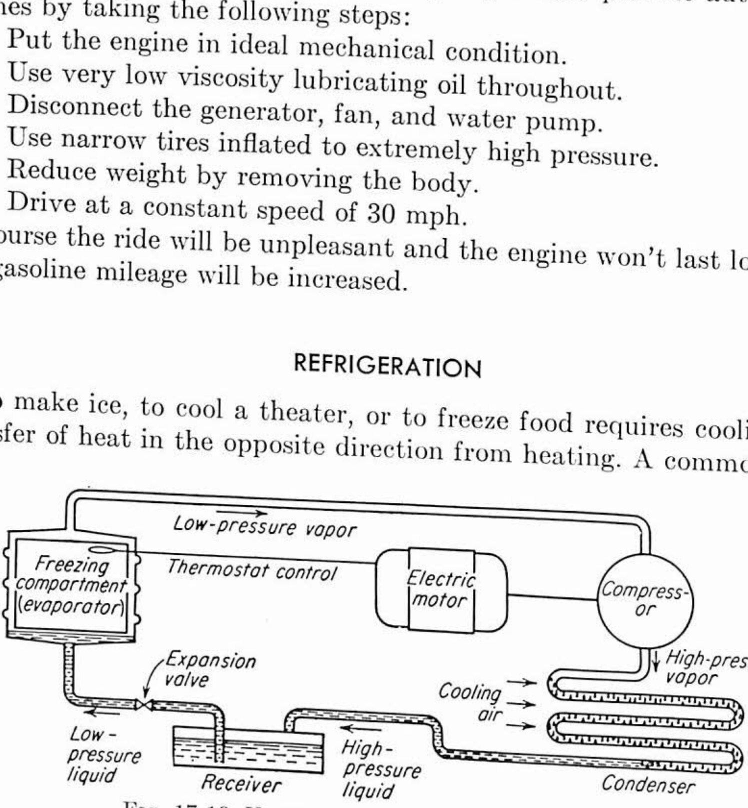


Fig. 17-10. Vapor compression refrigeration cycle.

Vapor-compression Refrigeration

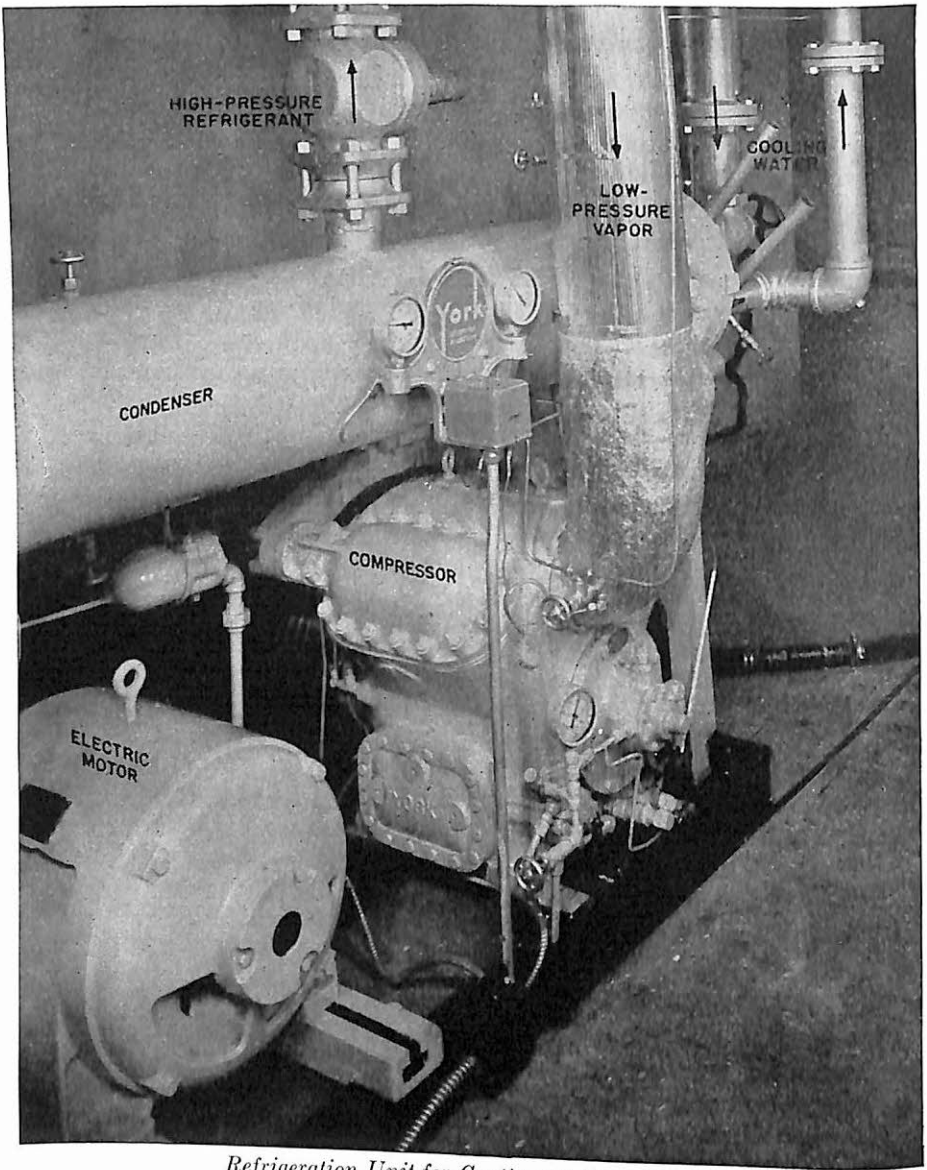
The vapor-compression-refrigeration cycle is essentially the reverse of the steam-power-plant cycle. As indicated in the figure, mechanical work is supplied to the *compressor* by the electric motor. The compressor raises the pressure and the temperature of the refrigerant and sends it through the *condenser*, where it is cooled and condensed by the relatively cooler room air and collected in the *receiver*. The high-pressure liquid refrigerant then passes through a narrow restriction called an *expansion valve* which controls the flow and separates the high-pressure part of the system from the low-pressure region. At low pressure the refrigerant boils at a low temperature and absorbs heat from the contents of the box and freezing compartment. The vaporized refrigerant with its increased internal energy then goes to the compressor, and the cycle is repeated.

Compare the refrigeration cycle with that of the steam power plant on page 291, and note the corresponding elements. Heat is added to the working fluid in the generator in one case and in the freezing compartments in the other. In both cases heat is rejected in the condenser, and the sump and receiver perform similar functions. However, work is done *by* the fluid in the turbine, whereas work is done *on* the fluid by the compressor. Another difference is that work is done *on* the condensed steam by the pumps whereas work could be obtained *from* the liquefied refrigerant in the expansion process. (Actually the cheaper, more trouble-free valve is used instead of a fluid motor to produce the desired pressure drop.)

The Refrigerant

Almost any fluid, even air or steam, could be used as a refrigerant. The properties which make a desirable refrigerant can be discovered by studying the processes involved in the thermodynamic cycle. To keep the quantity of refrigerant low (and therefore the pump work small), the fluid can be evaporated while it is absorbing heat to take advantage of the high heat of vaporization. Since the temperature at which a substance boils depends on the pressure, the operating pressures must be properly chosen. Steam has a high heat of vaporization, but in order to make it boil at a useful temperature, say 32°F, the pressure must be reduced to less than 0.1 psia or to a *vacuum* of 14.6 psi, and such a low pressure is rather difficult to maintain.

One requirement, therefore, is that the refrigerant shall boil at a desirable temperature, say 15°F in a household refrigerator, at an easily maintained pressure. On the other hand, the pressure required to condense the vapor at a practical temperature, say 100°F for cooling in room air, should



Refrigeration Unit for Continuous Food Freezer

This unit supplies refrigeration for a high-speed, completely automatic freezer which can freeze thousands of food packages per hour. Evaporation of the liquid refrigerant in the freezing tunnel absorbs heat from the warmer food. The low-pressure vapor returns to the compressor which raises the pressure and temperature. The condenser cooling water carries away the heat absorbed in the freezer plus the heat equivalent of the work done by the compressor. (*York Corporation.*)

not be so high that compression is difficult. In addition, for household use, the refrigerant should be nontoxic and noninflammable.

Air, ammonia, carbon dioxide, sulfur dioxide, and steam are used in commercial or domestic refrigeration under various circumstances, but each of these naturally occurring substances has one or more disadvantages. True to form, engineering scientists have attempted to improve on nature by developing made-to-order refrigerants. One successful attempt resulted in a series of substances called Freons developed from methane (CH_4) and ethane (C_2H_6) with some of the hydrogen atoms replaced by chlorine and fluorine atoms. One of these, Freon-12 (dichlorodifluoromethane, CCl_2F_2), is particularly good for domestic refrigerators because it is nontoxic and noninflammable and its properties are otherwise suitable. At a temperature of 15°F Freon-12 boils at a pressure of 32.4 psia, and at a temperature of 100°F it condenses at a pressure of 131.6 psia. What is the refrigerant in your refrigerator?

Refrigeration Calculations

The purpose of a refrigeration machine is to transfer heat by the expenditure of mechanical energy. In the heat engines previously discussed some of the input energy was *converted* to work and the performance was measured by efficiency, output over input. In refrigeration, however, the work done serves to transport the heat from a low temperature to a higher temperature and the useful output, refrigeration effect, may be (and often is) greater than the work input. The effectiveness of the process is measured by the *coefficient of performance* (COP), where

$$\text{COP} = \frac{\text{heat removed}}{\text{work required}}$$

Values of COP for modern refrigeration units may run from 3 to 5.

In rating commercial refrigerating plants, the Btu per minute is too small a unit for convenient use. The American Society of Refrigeration Engineers uses a unit based on ice-making ability, reflecting the primary use of the first refrigeration machines. A machine which can convert one ton of water at 32°F to ice in one day is said to have a capacity of one *ton* of refrigeration. Since the heat of fusion of ice is 144 Btu per lb, freezing 1 ton of ice per day requires

$$144 \text{ Btu/lb} \times 2{,}000 \text{ lb/day} = 288{,}000 \text{ Btu/day or } 200 \text{ Btu/min}$$

Referring to a machine as a "5-ton unit" means that the rate of refrigeration is 5 × 200 = 1000 Btu/min.

EXAMPLE: In a certain quick-freeze plant the refrigeration machine is to remove 1500 Btu per min from the cold room. Assuming a COP of 5 and a compressor efficiency of 75 per cent, calculate

1. The rating of the necessary unit
2. The rating of the driving motor
3. The heat which must be rejected by the condenser

1. Rating in tons $= \dfrac{\text{heat removed in Btu/min}}{200 \text{ Btu/min per ton}} = \dfrac{1500}{200} = 7.5$ tons

2. Since COP = (heat removed)/(work input), the net work input by the compressor must be

$$W_c = \frac{\text{heat removed}}{\text{COP}} = \frac{1500}{5} = 300 \text{ Btu/min}$$

For a compressor efficiency of 75 per cent, the driving motor must supply W_m = compressor work/efficiency = 300/0.75 = 400 Btu/min. But 1 hp = 42.42 Btu/min; therefore,

$$W_m = \frac{400}{42.42} = 9.5, \text{ or approximately 10 hp}$$

3. The approximate heat balance for the refrigeration process is: Heat added *to* + work done *on* = heat rejected *by* the working fluid, or

$$Q_a + W = Q_r$$

Therefore,

$$Q_r = 1500 + 300 = 1800 \text{ Btu/min}$$

to be carried away by the condenser cooling water.

Heat Pump

In the preceding example, 300 Btu of work delivered 1800 Btu of heat to the condenser. This illustrates the possibility of using a refrigeration unit as a *heat pump* for space heating. Heat may be absorbed by the refrigerant from water, the earth, or the air and delivered to the room being heated. The advantage of this arrangement is that the heat transferred may be several times the energy equivalent of the work done. However, the electrical energy required is usually much more expensive than common fuels and the installation is much more expensive than the usual furnace. In areas where fuel is expensive and electricity is cheap and where the same equipment can be used to heat a building in winter and cool it in summer, the heat pump shows attractive possibilities.

THE IMPORTANCE OF THERMODYNAMICS

Engineers are continually faced with problems involving the production, distribution, and conversion of various forms of energy, of which heat is one of the most widely used. In the last century tremendous progress has been made in discovering new knowledge of thermodynamics and applying it to practical developments. At present there is a great deal of engineering activity in conjunction with jet engines, gas turbines, heat pumps, heat transfer in nuclear reactors, and applications of heat energy in industrial processing. Transportation, manufacturing, food preservation, and human comfort all depend on the proper application or removal of heat.

Only a few of the multitude of applications of thermodynamics in engineering have been mentioned here. Like other engineering sciences, thermodynamics is based upon physics, chemistry, and mathematics; a strong foundation in basic science is necessary before you can begin to obtain the knowledge of this important field required in engineering.

ASSIGNMENTS

17-1. Describe, by means of sketches and two or three short paragraphs of explanation, the operation of one of the following thermodynamic devices: gas turbine, jet engine, heat pump, nuclear power plant, solar engine, vacuum refrigeration system. Information may be obtained from encyclopedias, textbooks, or popular magazines. Observe good report form in your description.

17-2. Select one of the devices listed in 17-1, and study the most recent developments in that field as described in current articles. In a two-page report list and describe briefly some of the technical problems which are now being solved by engineers in the field.

17-3. Give specific examples indicating where, in an automobile engine, in a television set, and in a refrigerator, heat transfer takes place by conduction, convection, and radiation.

17-4. An inventor claims that his new engine will produce 100 hp while burning 12 lb per hr of gasoline with a heating value of 21,000 Btu per lb. Discuss this claim from an engineering viewpoint.

17-5. The inventor of 17-4 changes his claims to 100 hp at a fuel rate of 25 lb per hr. Investigation reveals that the highest temperature in the cycle is 650°F. Discuss this claim in terms of the laws of thermodynamics.

EXERCISES: Assignments 17-6 to 17-18 are idealized problems to illustrate principles.

17-6. Find the centigrade scale equivalents of the following Fahrenheit temperatures: 68°, 392°, 14°, $-30°$.

17-7. If the temperatures listed in 17-6 were in degrees centigrade what would be the Fahrenheit equivalents?

17-8. If a 10-lb iron casting (specific heat = 0.105) at 250°F is dropped into 20 lb of water at 80°F, find the resultant temperature of the combination assuming that all the heat given up by the iron is absorbed by the water. (Answer: 88.5°F)

17-9. How many Btu were gained by the water in 17-8?

17-10. Calculate the rate of heat loss in Btu per hour per square foot through a 6-in. concrete slab with a 20°F temperature difference.

17-11. At 70°F, a given quantity of acetylene gas occupies a volume of 0.8 cu ft at a pressure of 65 psig. Find the pressure required to reduce this volume to 0.4 cu ft at the same temperature. (Answer: 145 psig)

17-12. A cylinder of oxygen is heated from 40 to 140°F. If the initial gage pressure was 20 psi, find the final pressure.

17-13. A given quantity of air occupies a volume of 2 cu ft at atmospheric pressure at 60°F. If the temperature is increased to 240°F and the pressure increased to 40 psig, find the new volume.

17-14. A reciprocating steam engine with a cylinder 4 in. in diameter receives steam at 80 psi. Find the work done at this pressure in a stroke of 8 in. (Answer: 670 ft-lb)

17-15. A small steam power plant is to be designed so that the turbine converts to mechanical power 250 Btu from each pound of steam circulated. Calculate the pounds of steam to be supplied per hour for an output of 500 hp. If the thermal efficiency is 20 per cent, calculate the rate at which heat will be rejected to the condenser.

17-16. A bomber requires 12,000 hp to maintain cruising speed. If the engines operate at 25 per cent efficiency and burn gasoline with a heating value of 120,000 Btu per gal, approximately how many gallons will be consumed in an 8-hr trip? (Answer: 8,150 gal)

17-17. A 1-ton air-conditioning unit is powered by a $\frac{1}{2}$-hp motor. Calculate the coefficient of performance of the unit assuming that the compressor is 100 per cent efficient.

17-18. A 5-ton ice-making machine has a COP of 4. Calculate the heat that must be carried away by the condenser cooling water. (Answer: 1250 Btu per min)

PROBLEMS: Assignments 17-19 to 17-22 are engineering problems to be solved by the complete five-step approach outlined in Chap. 15. Your instructor will discuss with you the simplifying assumptions which can be made.

17-19. Determine the approximate number of strokes of an automobile pump required to inflate a 6.00 X 16 tire to a gage pressure of 30 psi.

17-20. A fish-packing company is installing a 10-ton ammonia refrigeration unit driven by a 15-hp electric motor. If the condenser cooling water absorbs 20 Btu per lb and costs 12 cents per 100 cu ft, calculate the monthly bill for cooling water.

17-21. An irrigation pump which delivers 400 gpm against a 200-ft head is to be driven by a diesel engine. During the summer months it runs continuously. If fuel is delivered once a week, how large a fuel tank is required?

17-22. An outside wall of a room is 12 ft 6 in. long and 8 ft high. The interior and exterior surfaces are wood, and the space between 2- by 4-in. studs is filled with rock wool. The temperature of the inside surface is 60°F, and that of the outside surface is 20°F. Approximately how many Btu per hour will be lost through the wall? (Hint: write an expression for total temperature drop as the sum of the individual temperature drops, remembering that Q/A is the same through all parts of the wall.)

18

PREVIEW OF ELECTRODYNAMICS

Electrical energy is a relatively expensive form of energy because it must be obtained from other forms by means of costly equipment. However, the high cost of electrical energy is more than offset by the ease and efficiency with which it can be generated, transmitted, and distributed and by the precision with which it can be controlled and converted into other forms. "Electrodynamics" means the science of generation, conversion, and control of electrical energy.

The origin of electrical science goes back to the time of Thales of Miletus (*circa* 640–546 B.C.) who was aware that after amber is rubbed, it is able to attract light particles. There is some evidence that the Chinese knew of the magnetic properties of the lodestone nearly 2,000 years ago and used a magnetized needle for a compass nearly 800 years ago. Electrical phenomena received a great deal of attention from European and American scientists all during the eighteenth century, but they were limited in their study to static electricity which could be generated by crude machines and stored in condensers called Leyden jars. The invention of the voltaic cell (Volta, 1800) made available a steady flow of electrical current, and great progress was made in the next half century.

Many of the fundamental principles of electrical engineering were established before the nature of electricity was understood. Near the end of the nineteenth century, J. J. Thomson performed a series of experiments on what were called "cathode rays" using an evacuated tube very similar to the modern television "picture tube." As a result of his work and that of other scientists, it became clear that a cathode ray consists of a stream of negatively charged particles called *electrons.* Robert Millikan developed a refined method of measuring the quantity of electricity represented by one electron and using Thomson's data calculated the mass of the electron to be 9.11×10^{-28} gram.

In 1913 Niels Bohr proposed the theory that all atoms consist of a small, dense *nucleus* carrying a positive charge and surrounded by one or more orbital electrons. The simple hydrogen atom consists of a nucleus with one positive charge and a single planetary electron. The helium atom contains two planetary electrons and a nucleus with two positive charges. The lithium atom (atomic number = 3) contains a nucleus with three positive charges and three planetary electrons, two following one orbit and the third in an outer orbit, or *shell*. Sodium (atomic number = 11) has eleven planetary electrons, two in the first shell, eight in the second, and one in the third.

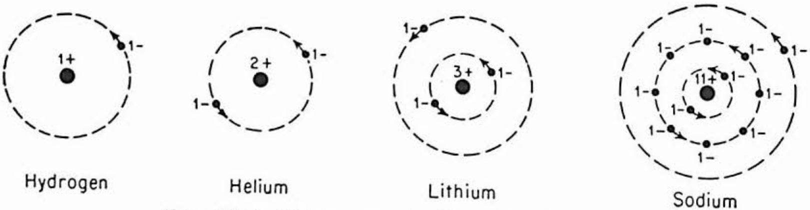


Fig. 18-1. Bohr concept of atomic structure.

In a similar way every atom from the simplest, hydrogen, to the most complex, uranium, can be constructed on the basis of the Bohr concept. A great deal has been learned about the nucleus since Bohr made his proposal. However, the Bohr atom is consistent with all observations and is satisfactory for explaining most of the phenomena of interest to engineers. For example, a good electrical conductor is a material in which the electrons in the outer shell are *free*, whereas in an insulator the electrons are tightly bound to their atoms. An electric *current* consists of a flow of these free electrons.

The emphasis in this chapter is on those aspects of electrodynamics which are of importance in engineering. After the basic electrical quantities are defined, the experimental laws which govern electrodynamic behavior are described and formulated. These laws are then applied to problems involving electrical circuits, generators, motors, transformers, lights, and electronic devices.

DEFINITION OF ELECTRICAL QUANTITIES

The basic factors are *charge*, *current*, *voltage*, *power*, and *energy*. The symbols, definitions, and engineering units for these factors are as follows:

Q = charge = quantity of electricity, coulombs
I = current = rate of flow of charge, coulombs per sec, or amperes
E = voltage = energy per unit charge, volts
P = power = energy per unit time, watts or kw
W = energy = power times time, watt-sec or kwhr

Since $$I = \frac{Q}{T} = \text{charge per unit time}$$

and $$E = \frac{W}{Q} = \text{energy per unit charge}$$

then $$E \times I = \frac{W}{Q} \times \frac{Q}{T} = \frac{W}{T} = \text{energy per unit time} = \text{power}$$

or $$E \times I = P \text{ in watts}$$

Note that it is the *average power* which is of interest in engineering; if the voltage and current vary with time instead of being constant, the product must be handled so that average power is obtained. The total energy is

$$W = E \times I \times T = P \times T \text{ in watt-sec}$$

EXPERIMENTAL LAWS

The science of electrical engineering is based on a series of experimental laws established by careful observation and measurement. In this introductory discussion only a few can be mentioned.

Electric Charge and Potential

The early experimenters working with static electricity made use of the fact that electric charge can be stored in a *condenser* consisting of two conducting plates separated by an insulator. Charge is built up on a condenser by removing electrons from one surface or *plate*, leaving it charged positively, and adding electrons to the other plate, making it negative. Removal of the electrons from normally neutral atoms leaves them deficient in negative charge and therefore positively charged. Separation of the charge requires work; this work can be in the form of mechanical friction, as in rubbing amber with fur or running a hard-rubber comb through hair. The charges when separated represent potential energy which is converted to light, sound, and heat energy when the condenser is discharged.

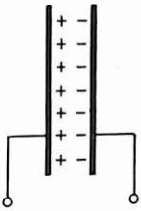


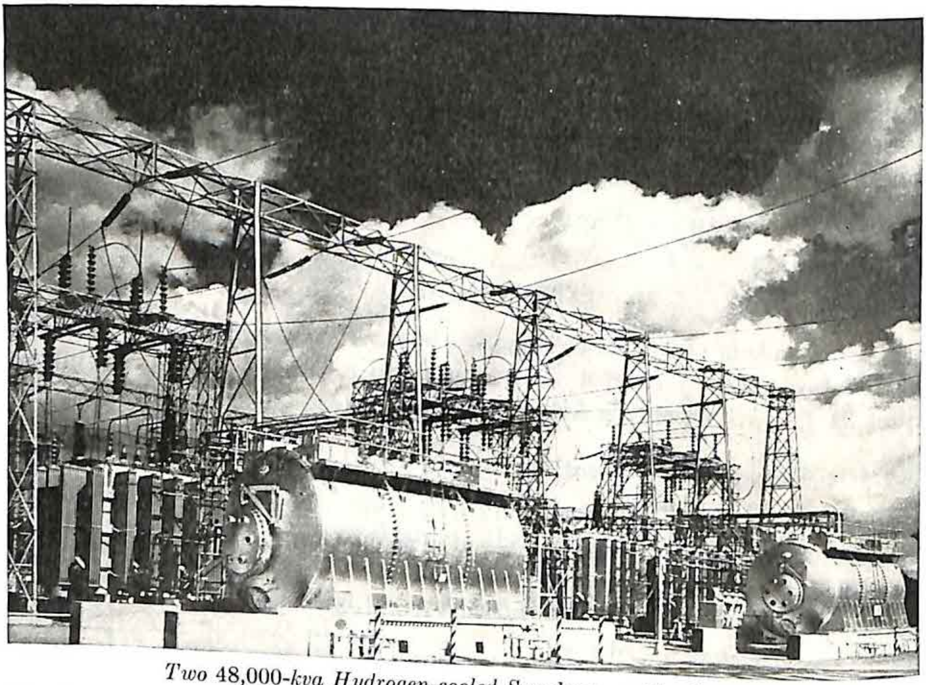
FIG. 18-2. Charged condenser.

The electrical potential, or voltage, on a condenser is a measure of the energy stored per electron (or per unit charge) and is measured in volts. It was determined experimentally that the charge Q was directly proportional to voltage E, or

$$Q = CE$$

The constant of proportionality C is defined as the *capacitance* of the condenser and is measured in farads. The capacitance is a property of the condenser depending on the area and separation of the plates and on the material used as an insulator.

Just how is energy stored in a condenser? Consider for a moment the storage of potential energy by lifting a mass from the earth's surface. The attraction of gravity pulls all massive objects toward the earth. Work is done in separating the mass from the earth. Between the mass and the earth there exists a gravitational *field*. The direction of the field is the direction of the force, downward; the strength of the field is measured by the force on a unit mass. In an analogous way, there is an *electric attraction* between unlike charges, and work is required to separate them. Whenever charge exists, energy is stored in an *electric field*. Capacitance is a measure of the ability of a condenser to store electric field energy.



Two 48,000-kva Hydrogen-cooled Synchronous Condensers

One important application of large condensers is in voltage control at the end of a long transmission line. Power is generated in the mountains and transmitted 150 miles to a substation near an industrial center. To control the voltage as the industrial load changes throughout the day, the condenser action of these huge devices is varied. (*General Electric Company.*)

EXAMPLE: What average current will be required to charge a 120-microfarad (μf) condenser to a voltage of 1,000 volts in 0.02 sec?

$$Q = CE$$

but

$$I = \frac{Q}{T} = \frac{CE}{T}$$

Therefore, $$I = 120 \times 10^{-6} \frac{1000}{0.02} = 6 \text{ amp}$$

EXAMPLE: How much energy is stored in the electric field of the condenser?

Since $E = Q/C = IT/C$, the voltage builds up as the current flows. The average voltage during charging at constant current is $\frac{1}{2}E$. The average power is $P = (\frac{1}{2}E)(I) = (\frac{1}{2} \times 1{,}000)(6) = 3{,}000$ watts. The total energy is $W = PT = \frac{1}{2}EIT = 3{,}000 \times 0.02 = 60$ watt-sec.

Ohm's Law

When a voltage exists across the terminals of a conductor, the negative charge at one end tends to repel the adjacent free electrons. These move away and in turn repel the free electrons on adjacent atoms. In this way electrons "flow" along a conductor, and the flow constitutes an electric current. The charge carried by each electron is so small that a current of 1 amp represents a flow of 6,300,000,000,000,000,000 (6.3×10^{18}) electrons per second! Since $P = E \times I$, the current taken by a 100-watt light operating at 120 volts is

$$I = \frac{P}{E} = \frac{100}{125} = 0.8 \text{ amp}$$

How many electrons per second?

George Ohm is famous for his observation that the current which flows in a given conductor is directly proportional to the voltage across it. Ohm's law can be expressed mathematically as

$$E = RI$$

where E = voltage, volts
I = current, amp
R = a constant of proportionality called *resistance*
and measured in ohms. The resistance of the 100-watt light under operating conditions is

$$R = \frac{E}{I} = \frac{125}{0.8} = 156 \text{ ohms}$$

The resistance of a conductor is directly proportional to its length, inversely proportional to its cross-sectional area, and dependent on the composition and temperature of the material.

EXAMPLE: The resistance of No. 10 gage pure copper wire is approximately 1.02 ohms per 1,000 ft at 80°F. If seven strands of No. 10 are combined in a cable, find the resistance of 1 mile of the cable.

Combining seven strands provides seven times the cross-sectional area. Therefore, the resistance of the cable is found from

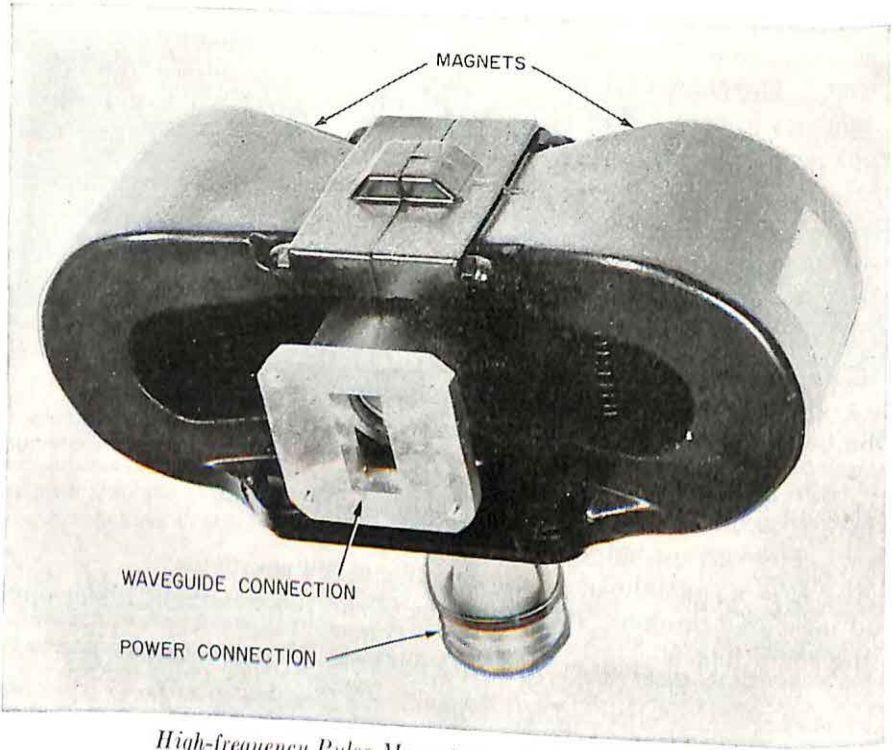
$$\frac{R_2}{R_1} = \frac{L_2}{L_1} \times \frac{A_1}{A_2}$$

or

$$R_2 = R_1 \frac{L_2}{L_1} \times \frac{A_1}{A_2} = 1.02 \times \frac{5{,}280}{1{,}000} \times \frac{1}{7} = 0.77 \text{ ohm}$$

Magnetism

As was demonstrated by Sir William Gilbert, the earth is a great magnet with the *North Magnetic Pole* located in northern Canada and the *South Magnetic Pole* almost diametrically opposite. The *magnetic field* of the earth results in an attraction between the north pole of any magnet



High-frequency Pulse Magnetron with Integral Magnets

The relationship between electricity and magnetism provides many of the most important applications of electrodynamics. In the simple electromagnet, a flow of electric current produces a magnetic field. In the magnetron, electrons emitted from a central cathode (not visible) follow paths determined by the magnetic field set up by the external horseshoe magnets. The shape of the path followed by the electrons results in their giving up and absorbing energy from the surrounding field. The high-frequency energy output is available for transmission along the rectangular waveguide at the front. For 5 microseconds, this magnetron will produce 250 kw of power at 10,000 megacycles. (*Litton Industries.*)

and the North Magnetic Pole (a south pole). At the other extreme of size, certain atoms are miniature magnets. In iron, nickel, or cobalt, these magnetic atoms group together to form crystals with all north poles similarly aligned. Crystals in turn group together to form elementary magnets. In an "unmagnetized" piece of iron or steel, these elementary magnets are present but, being oriented at random, they have no net magnetic effect. *Magnetization* consists of aligning the elementary magnets so that they are all parallel to each other and their effects are cumulative.

Electricity and Magnetism

Hans Christian Oersted is credited with the discovery of the relation between electricity and magnetism. Placing a wire carrying an electric current over and parallel to a compass needle, he was amazed to see the needle deflect. He interpreted this result as indicating that there is a magnetic field about any wire carrying an electric current. André Ampère then discovered that a loop of wire or a coil of several turns ("solenoid") acted as a magnet with a north pole at one end and a south pole at the other. A few years later William Sturgeon produced a powerful electromagnet by winding a solenoid on a core of soft iron. The resultant effect was a combination of the magnetic effects of the coil and of the multitude of elementary magnets in the iron.

The Magnetic Field

Whenever there is electric charge in motion, energy is stored in the form of a magnetic field. The charge in motion may be an electron moving along its orbit as in an iron atom, it may be an electron speeding across an evacuated television tube, or it may be a stream of electrons in a conductor. Any field can be described by a pattern of lines indicating amount, direction, and concentration of the field. These lines are called lines of *flux* or flow because of their similarity to flow lines in a fluid stream. The total magnetic flux ϕ from the bar magnet (Fig. 18-3) is nine lines, or nine kilolines if one dotted line represents 1,000 units of flux. The direction of the field at any point is indicated by the direction a compass needle at that point would take. The concentration or *flux density* B is measured in lines per square inch and is high near the poles and low out at some distance.

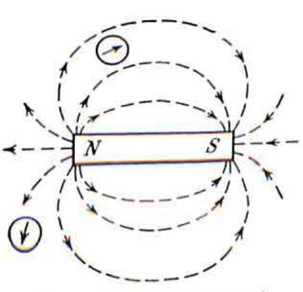


Fig. 18-3. Bar magnet.

In an electromagnet, the total flux is directly proportional to the number of turns and the current and inversely proportional to a property of the flux path called the *reluctance* $\mathcal{R}$. Expressed symbolically,

$$\phi = BA = k\frac{NI}{\mathcal{R}}$$

where k is a constant of proportionality. In the sketch of the air-core coil (Fig. 18-4), five turns carrying 0.002 amp (say) produce a total of five lines of flux ($k/\mathcal{R} = 500$). When the iron core is inserted, the total flux is increased to nine lines, indicating that the presence of the iron reduces the reluctance of the path. The greatest gain is in flux density at the end of the coil; notice how much closer together the lines are in Fig. 18-5. In general, the purpose of electromagnets is to produce a concentrated field with high magnetic flux density.

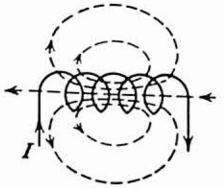


FIG. 18-4. Air-core coil.

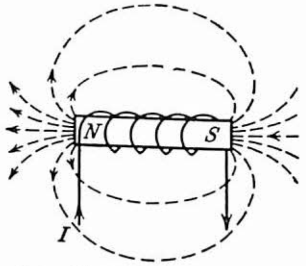


FIG. 18-5. Iron-core coil.

Force on a Conductor in a Magnetic Field

Michael Faraday was the first person to obtain mechanical motion due to the interaction of an electric current and a magnet. He discovered that if a conductor carrying current into the paper (Fig. 18-6) is placed in a magnetic field as shown, there will be a resultant force downward. This force is due to the reaction of the field around the wire on the field due to the magnet. The force is proportional to the flux density in the field, the length of the conductor in the field, and the current in the conductor.

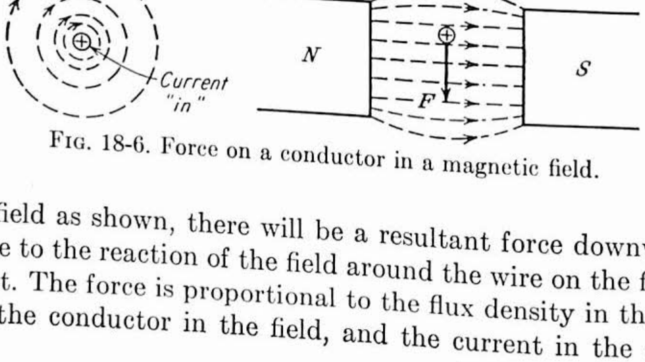


FIG. 18-6. Force on a conductor in a magnetic field.

Expressed symbolically,

$$F = BLI \times 1.06 \times 10^{-6}$$

where F = force, lb
B = flux density, lines per sq in.
L = length of conductor, ft
I = current, amp

This relationship is the basis for motor action and is applied frequently in engineering.

Electromagnetic Voltage Generation

The second great discovery by Faraday came soon after. He reasoned that if a wire carrying a current tends to move in a magnetic field, then motion of the wire in a magnetic field might tend to produce a current. When he thrust a bar magnet into a coil, a sensitive galvanometer indicated that a current was generated. If the coil is not part of a closed circuit, a voltage will appear across the coil terminals. The voltage generated, or *induced*, is proportional to the rate at which flux lines are cut by the conductor, and it makes no difference whether the coil moves or the magnet moves as long as there is relative motion. The relation can be expressed as

$$E = \frac{\phi}{T} \times 10^{-8}$$

where E = generated voltage, volts
ϕ = magnetic flux cut, lines
T = time, sec

This relationship is basic to the operation of generators, transformers, and many other electrical engineering devices.

Self-induction

Voltage is induced in a conductor whenever flux lines are cut. A case of special interest is where the flux lines cut the conductor which produces them. Assume that Fig. 18-7 illustrates the field set up by a current of 0.5 amp in a 200-turn coil with each dotted line representing 1,000 lines of flux. If the current is reduced to zero in 0.001 sec, the field disappears and the effect is as if the 5,000 lines of flux cut the 200 turns. The voltage per turn is

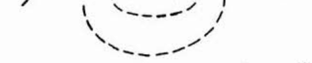


FIG. 18-7. Field around a coil.

$$E = \frac{\phi}{T} \times 10^{-8} = \frac{5{,}000}{0.001} \times 10^{-8} = 0.05 \text{ volt}$$

The total voltage for 200 turns is 200 × 0.05 = 10 volts.

Since the flux is proportional to the current, and since the voltage is proportional to the rate of flux cutting, the voltage induced in such a coil must be proportional to the rate of change of current, or

$$E = L \frac{I_\Delta}{T}$$

where I_Δ = *change* in current in time T
L = coefficient of self-induction
or simply, the *inductance* measured in *henrys.*

For the coil sketched,

$$L = \frac{E}{I_\Delta / T} = \frac{10}{0.5/0.001} = 0.02 \text{ henry}$$

The inductance is a property of the coil and is a measure of the ability of the coil to store magnetic field energy. It can be shown (can you do it?) that the energy stored in a magnetic field is $\frac{1}{2}LI^2$; this is mathematically similar to the expressions for electric field energy $\frac{1}{2}CE^2$ and kinetic energy $\frac{1}{2}MV^2$. The inductance can be increased greatly by using an iron core, which increases the flux for a given current.

ELECTRIC CIRCUITS

Some physical phenomena may be described in terms of circuits, while others must be treated as fields. Circuit phenomena are those in which the variables depend only on position along the path; for example, many problems in hydraulics involve calculations of pressure and velocity variations along a pipe. The routing of raw materials in a factory may be handled as a circuit problem. The earth's gravitational effect, however, is three-dimensional, since it varies from point to point on the earth's surface and with distance from the center of the earth. Vacuum tubes, generators, and transmission lines involve fields in their operation; however, the usual approach in analysis or design is to replace these complex devices with *equivalent circuits.* In this way field problems become circuit problems, and therefore, skill in solving circuits is extremely important for electrical engineers.

Applications of Ohm's Law

The use of Ohm's law in circuit problems can be illustrated by some simple examples.

EXAMPLE: A heating unit draws 2.4 amp from a 6-volt battery. What is the resistance of the heater?

The lead-acid cell is a device for converting chemical energy to electrical energy. Three cells are grouped together to form the common 6-volt storage battery. The equivalent circuit consists of a voltage source E and a resistance R.

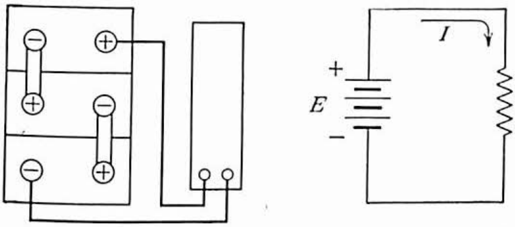


FIG. 18-8. Picture diagram and ideal equivalent circuit.

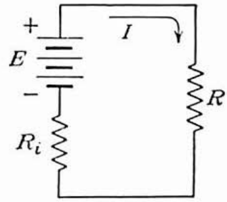


FIG. 18-9. Practical equivalent circuit.

From Ohm's law,

$$E = RI$$

or

$$R = \frac{E}{I} = \frac{6}{2.4} = 2.5 \text{ ohms}$$

A practical battery always has some internal resistance, which represents the fact that there is some loss in the energy conversion from chemical to electrical.

EXAMPLE: If the battery of the previous example has an internal resistance of 0.2 ohm, calculate the heater resistance, the power output, and the efficiency of the battery.

The new equivalent circuit includes R_i, the internal resistance. The total resistance is $R + R_i$. Therefore,

$$R + R_i = \frac{E}{I} = \frac{6}{2.4} = 2.5 \text{ ohms}$$

and

$$R = 2.5 - R_i = 2.5 - 0.2 = 2.3 \text{ ohms}$$

The voltage output is the voltage across R, or

$$E_R = RI = 2.3 \times 2.4 = 5.52 \text{ volts}$$

$$\text{Power output} = P = E \times I = 5.52 \times 2.4 = 13.25 \text{ watts}$$

$$\text{Voltage across } R_i \text{ is } E = R_i I = 0.2 \times 2.4 = 0.48 \text{ volt}$$

$$\text{Power loss in the battery is } P = EI = 0.48 \times 2.4 = 1.15 \text{ watts}$$

$$\text{Battery efficiency} = \frac{\text{output}}{\text{input}} = \frac{\text{output}}{\text{output} + \text{losses}} = \frac{13.25}{13.25 + 1.15} = 92\%$$

Power in a Resistance. Ohm's law provides a different approach to calculating power in a resistance. Since $E = RI$,

$$P = EI = (RI)I = I^2R = E\frac{E}{R} = \frac{E^2}{R}$$

Use these relations to check the power calculations in the example.

ELECTRIC GENERATORS

Since voltage is energy per unit charge, voltage can be produced by any means which will convert energy from some other form to electrical. Chemical energy is utilized in the common battery. Heat energy is used in the *thermocouple* employing a junction of dissimilar materials. Light energy falling on sensitive surfaces in a *light meter* generates measurable voltages. The most important method of generating voltage for electric power employs Faraday's electromechanical principle involving the motion of a conductor in a magnetic field.

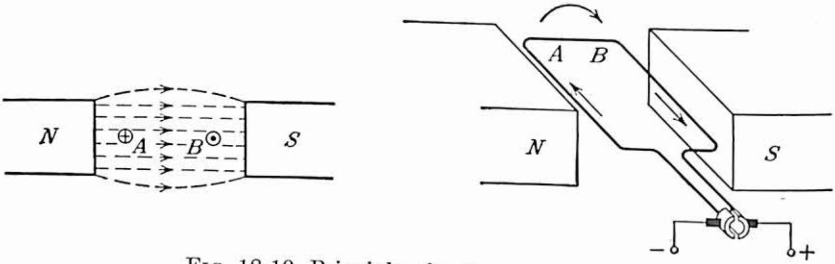


FIG. 18-10. Principle of voltage generation.

When the conductor *A* (Fig. 18-10) is moved upward across the lines of flux from the north pole, a voltage is induced which makes the back end positive with respect to the front end. If a similar conductor *B* moves downward across the flux lines, the induced voltage makes the front end positive with respect to the back. If the two conductors are connected to form a loop and rotated together, the voltages add and the total is available at the *brushes*, contacts sliding on the *split-ring commutator*. The commutator reverses the external connections when conductor *A* is at the top, so that as *A* starts down across the flux lines, the current in the external circuit remains in the original direction.

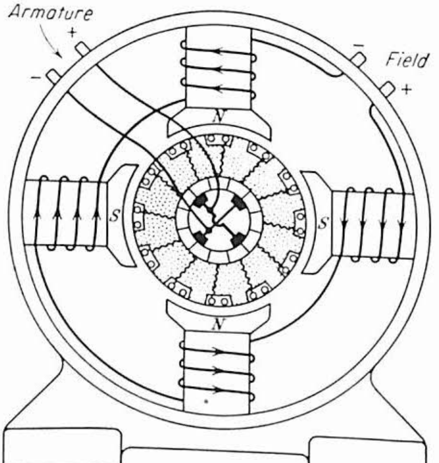
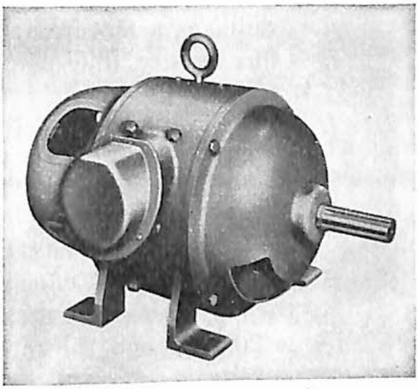


FIG. 18-11. Practical four-pole d-c generator.

The practical generator employs this same principle but differs greatly in form. Many conductors are connected in series to provide a greater voltage. In Fig. 18-11, each small circle represents a bundle of conductors. The conductors are placed in slots in a cylindrical iron *armature* to reduce the reluctance of the magnetic path. The *commutator* is split into as many segments as there are groups of conductors. Four or more *poles* are generally used to take advantage of the full circumference of the armature. The strong magnetic field is supplied by electromagnets energized by the *field winding*.



Commercial Direct-current Generator

This general-purpose generator is available in ratings from ½ to 150 kw at 125 or 250 volts. A somewhat similar generator is probably in your school's electrical laboratory. Study the actual machine and identify the armature, windings, poles, commutator, and brushes. (*Westinghouse Electric Corporation.*)

In one revolution each conductor cuts all of the flux from all of the poles and generates a voltage.

$$E/\text{cond} = \text{flux/pole} \times \text{poles/revolution} \times \text{revolutions/sec} \times 10^{-8}$$

$$E/\text{cond} = \phi P \frac{N}{60} \times 10^{-8}$$

If there are Z conductors connected in series, the total voltage is

$$E = \phi P \frac{N}{60} Z \times 10^{-8}$$

EXAMPLE: The four-pole generator sketched in Fig. 18-11 has a flux of 1 million lines per pole, has 150 conductors in series, and turns at 1,200 rpm. Calculate the generated voltage.

$$E = \phi P \frac{N}{60} Z \times 10^{-8} = 10^6 \times 4 \frac{1{,}200}{60} \times 150 \times 10^{-8} = 120 \text{ volts}$$

ELECTRIC MOTORS

A conductor carrying a current in a magnetic field is acted on by a force tending to push the conductor across the field. Referring to the sketch of the elementary generator, if conductor A carries a current out of the paper, it will receive an upward force. If B carries a current into the paper, it will receive a downward force. If the positive (+) and negative (−) terminals are connected to the corresponding terminals of a battery or generator, the loop will tend to rotate in the indicated direction. Now electrical energy is being converted into mechanical energy.

The practical generator of Fig. 18-11 can serve equally well as a motor. The turning effect or torque produced is

$$T = (nF)R = n(1.06BIL \times 10^{-6})R$$

where T = torque, lb-ft
n = number of active conductors
F = force per conductor, lb
R = radius of armature, ft
B = flux density, lines per sq in.
I = current, amp
L = length of conductor, ft

EXAMPLE: A four-pole motor similar to the sketch has a flux of 1 million lines per pole and a pole face area of 40 sq in. At any one time there are under each pole face four bundles containing 10 conductors each. The effective length of the conductors is 9 in., and the diameter of the armature is 12 in. If the conductor current is 20 amp and the motor speed is 1,800 rpm, calculate the developed power.

The force on each conductor is

$$F = 1.06 \frac{\phi}{A} IL \times 10^{-6} = 1.06 \frac{10^6}{40} 20 \times \frac{9}{12} \times 10^{-6} = 0.4 \text{ lb}$$

The number of active conductors is

$$n = 10 \text{ per bundle} \times 4 \text{ bundles per pole} \times 4 \text{ poles} = 160$$

The developed torque is

$$T = nFR = 160 \times 0.4 \times 0.5 = 32 \text{ lb-ft}$$

The developed power is

$$P = \frac{2\pi NT}{33{,}000} = \frac{2\pi \times 1{,}800 \times 32}{33{,}000} = 11 \text{ hp}$$

RATINGS AND EFFICIENCY

When a motor name plate says "10 hp," just what does that mean? When a rope is rated for a 200-lb pull, it means that a pull in excess of that figure may break the rope. When a beam is rated for a load of 10 tons, it means that a load greater than that may cause excessive deformation. When an automobile engine is rated at 162 hp, that is the maximum power which can be produced. However, a 10-hp electric motor may develop 20 or even 50 hp—for a short period of time.

Ratings

Every electric motor and generator converts some of its input energy into heat. The current in the field and armature conductors produces heat equal to the square of the current times the resistance (I^2R losses). The changing magnetic fields in the field poles and armature core result in heat (iron losses). The motion of the armature through the air and the turning of the shaft in the bearings produce heat (windage and friction losses). These losses must be dissipated, usually by radiation, conduction, and convention, to the surrounding air and objects. The temperature of the machine rises until the heat carried away is just equal to the heat produced.

A "10-hp motor" will produce 10-hp output continuously and dissipate the accompanying losses without causing the temperature to rise above safe limits. If the operating temperature is too high, the insulation around the conductors deteriorates rapidly and breakdown will occur prematurely. A modern electric motor will operate at rated load almost indefinitely. Motors have been known to operate continuously for many years with no attention whatsoever.

On the other hand, a "10-hp motor" used intermittently may be loaded to 20 hp for a short period of time if allowed to cool down before the next loading. An automobile starter motor, for example, carries a much higher rating than a motor of comparable size designed for continuous service. For the same reason, the rating of a motor or generator can be increased by providing additional cooling. Modern machines include a fan as an integral part of the armature; the fan draws in cool air and forces it past the windings to carry away heat losses.

Efficiency

The efficiency of electric motors and generators ranges from 80 to 95 per cent, which is relatively high for rotating equipment. The performance of large equipment is usually determined by measuring the losses. For example, consider a generator rated at 100 kw, 250 volts, 400 amp at 1,800 rpm. In the laboratory, the generator is driven at rated speed with the field energized from an outside source to give rated output voltage. For this "no-load" condition, the input power is measured by a *dynamometer* to be 3.90 hp. The field current is 8.20 amp. The resistance of the armature circuit at operating temperature is 0.0320 ohm.

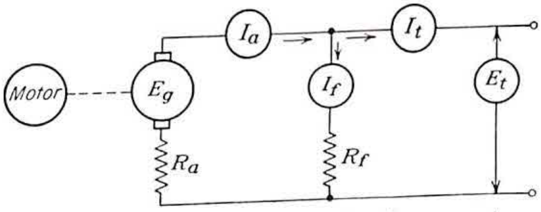


FIG. 18-12. Equivalent circuit of a d-c generator.

The equivalent circuit of the generator under operating conditions is as shown in Fig. 18-12. Note that $I_a = I_t + I_f$. The principal losses are the copper loss (I^2R) in the armature, the copper loss in the field, and the rotational losses, which include iron loss, windage, and friction. These are evaluated as follows:

Armature copper loss

$$= I_a^2R_a = (408.2)^2 \times 0.0320 = 5{,}330 \text{ watts} = 5.33 \text{ kw}$$

Field copper loss

$$= I_f^2R_f = E_tI_f = 250 \times 8.20 = 2{,}050 \text{ watts} = 2.05 \text{ kw}$$

Rotational loss

$$= \text{no-load input} = 3.90 \times 746 = 2{,}910 \text{ watts} = \underline{2.91 \text{ kw}}$$

$$\text{Total losses} = 10.29 \text{ kw}$$

$$\text{Efficiency} = \frac{\text{output}}{\text{output} + \text{losses}} = \frac{100}{100 + 10.29} = 90.6\%$$

Under any other load, the field and rotational losses remain approximately constant while the armature loss varies as the square of the output current. What would be the efficiency at half load?

DIRECT-CURRENT APPLICATIONS

The circuits and electrical devices discussed so far operate with an electric current which is continuous and unidirectional—so-called *direct current*. In the direct-current (d-c) generator, the commutator reverses the connections to the generating conductors so that the current in the external circuit always flows in the same direction.

There are several practical advantages in using direct current. Storage batteries must be charged with a continuous current and in turn yield direct current. Direct-current motors have excellent starting characteristics (high torque) and therefore are used on street railways and where motors must be started under load. In addition, the speed of d-c motors is readily controlled, and this characteristic is important in steel rolling mills, for example. Most vacuum tubes require d-c power supplies.

Edison's original central stations supplied direct current to his neighborhood customers. As the number of customers increased, the current demand mounted and larger conductors were required. Customers at a distance posed a difficult problem because the IR voltage drop consumed a considerable part of the available voltage and the I^2R losses were large.

Since voltage is energy per unit charge, more power can be transmitted with a given current at high voltage ($P = EI$). Taking advantage of this fact, Edison introduced the three-wire system in which the usable voltage is applied between each outer wire and a center, grounded wire. In essence, power is transmitted at double voltage, and for a given power the current is reduced to half. With a conductor of given resistance, the voltage drop is reduced to half and the I^2R losses reduced to one-quarter.

This helped to alleviate the immediate situation, but to handle today's tremendous demand for electrical power with direct current would require a central station in every large building or plant. The development of the practical *transformer*, which converts *alternating-current* (a-c) power from low to high voltage for efficient transmission and back to low voltage for safe application, marked the end of large-scale d-c transmission.

THE TRANSFORMER

In its simplest form, the transformer consists of two coils wound on a common iron core. The input (primary) and output (secondary) electrical circuits are interlinked or coupled by means of a magnetic circuit.

Principle of Operation

The operation of the transformer can be explained in terms of the discoveries of Sturgeon and Faraday. An alternating voltage applied to the primary coil causes an alternating current which produces a strong alternating magnetic flux in the closed magnetic circuit. The changing magnetic flux links both primary and secondary coils and induces a voltage in each. Under equilibrium conditions the voltage induced in the primary by the changing flux is just equal to the applied voltage. The voltage per turn (proportional to the rate of change of flux, see page 313) will be the same in both primary and secondary coils, since both link the same flux. The coil voltages, therefore, will be proportional to the number of turns, or

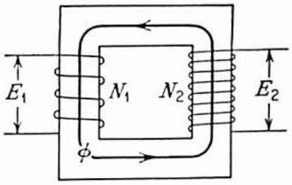


Fig. 18-13. The transformer.

$$\frac{E_2}{E_1} = \frac{N_2}{N_1}$$

EXAMPLE: A transformer is to be wound to step down from a 2,300-volt distribution circuit to 115 volts. If the magnetic core is such that 1.5 volts per turn is desirable, how many turns should be on the primary and secondary windings?

Since $E/N = 0.5$,

$$N_1 = \frac{2{,}300}{1.5} = 1533 \text{ turns}$$

and

$$N_2 = \frac{115}{1.5} = 77 \text{ turns}$$

Actually, the secondary winding would contain a few more turns to take care of the voltage drop in the transformer and still provide 115-volt output.

EXAMPLE: A heating load of 6 kw at 120 volts is to be supplied over No. 6 copper wire ($R = 0.4$ ohm per 1,000 ft) at a distance of 1,500 ft from the generator. Calculate the necessary generator voltage and the transmission efficiency.

The resistance per conductor is $0.4 \times 1{,}500/1{,}000 = 0.6$ ohm.

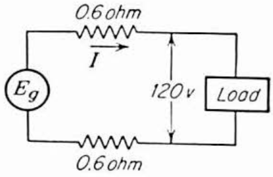


FIG. 18-14. Power transmission.

Since $P = EI$,

$$I = \frac{P}{E} = \frac{6{,}000}{120} = 50 \text{ amp}$$

By Ohm's law, voltage drop $= IR$

$$= 50(0.6 + 0.6) = 60 \text{ volts.}$$

Therefore, the generator voltage must be

$$E_g = E_l + IR = 120 + 60 = 180 \text{ volts}$$

The transmission losses are

$$I^2R = (50)^2(1.2) = 3{,}000 \text{ watts}$$

The efficiency of transmission is

$$\frac{\text{Output}}{\text{Input}} = \frac{\text{output}}{\text{output + losses}} = \frac{6{,}000}{6{,}000 + 3{,}000} = 67\%$$

EXAMPLE: If the load in the preceding example is supplied at 480 volts over the same line, calculate the generator voltage and transmission efficiency.

Now the current is

$$I = \frac{P}{E} = \frac{6{,}000}{480} = 12.5 \text{ amp}$$

The losses are $I^2R = (12.5)^2(1.2) = 188$ watts

The generator voltage must be

$$E_l + IR = 120 + (12.5 \times 1.2) = 135 \text{ volts}$$

The transmission efficiency is $\dfrac{6{,}000}{(6{,}000 + 188)} = 97$ per cent.

These examples illustrate the advantage of being able to transmit power at high voltage, which has resulted in the use of transmission voltages as high as 330,000 volts. Because it is not practical to generate or apply power at such high voltages, transformers are used to transform the generator output up to the transmission voltage. Near an industrial center, the voltage is stepped down for distribution and then down still further for application.

ALTERNATING CURRENTS

But a transformer works only on a voltage which is changing with time. The most convenient form of alternating voltage is one where the value at any time is proportional to the sine of the angle of rotation of the generator which is proportional to time. Such a *sine wave*, shown in Fig. 18-15, would be generated by a conductor moving up past a north pole and down past a south pole without a commutator to reverse the connections.

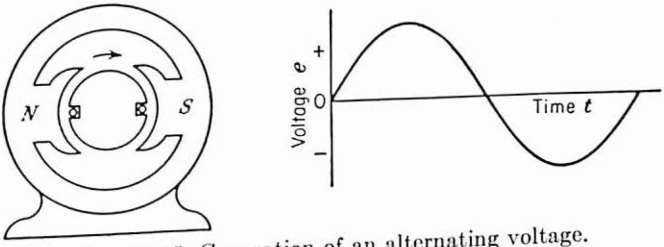


FIG. 18-15. Generation of an alternating voltage.

Sine Waves

It was pointed out (page 308) that the current flowing in a condenser is proportional to the rate of change of voltage and that (page 314) the voltage across an induction coil is proportional to the rate of change of current. A sine wave has the unique property that its rate of change with time is just another sine wave. Note that if the solid line of Fig. 18-16 represents a sine wave of voltage, at time $t = 0$ the voltage is increasing rapidly and its rate of change (dotted line) is positive and a maximum. As the voltage increases, its rate of change decreases until when the voltage is a maximum (where the curve flattens out), the rate of change is zero. When the voltage begins to decrease, the rate of change is negative. It is seen that the dotted line is another sine wave displaced one-quarter cycle (this is called a 90° *phase* shift, since a cycle represents a full revolution, or 360°).

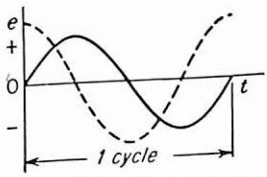


FIG. 18-16. Sine-wave relations.

Alternating-current Calculations

Special methods have been developed by electrical engineers for handling the complex calculations involving sine waves of voltage and current. In general, the voltage and current waves are out of phase as indicated in Fig. 18-17. Since voltage and current are not always in the same direction, the simple product of voltage times current is not equal to the power; a *power factor* related to the phase angle must be used. Since the voltage and current are continuously changing, a single representative value is needed for calculations. The *root-mean-square* (rms) or *effective* value turns out to be useful in power calculations, and a-c meters are calibrated on this basis. Trigonometry, complex notation, calculus, and vector analysis are all important mathematical tools used frequently by electrical engineers.

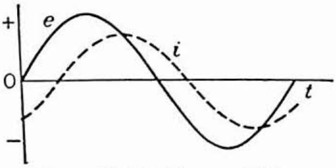


FIG. 18-17. Phase shift.

ELECTRONICS

In some ways the circuits of electrodynamics resemble the cycles of thermodynamics. For example, chemical energy is converted to electrical energy in a battery and the energy is added to a stream of electrons flowing in a conductor. Energy is extracted from the current at the load and converted to some other form—heat in the case of a resistor or mechanical energy in the case of a motor. The "working fluid" is the stream of electrons or current. Electrical engineering is concerned almost entirely with the addition of energy to a current in one portion of a circuit and the abstraction of energy in another. The energy transformations which involve individual electrons, as in a vacuum tube or in a neon sign, are considered as belonging to the special field of *electronics*.

The science of electronics had its start in an observation incidental to the development of the electric light. In 1883, Edison was experimenting with a carbon lamp in which he had sealed a metal plate. Perhaps he was planning to demonstrate the fact that the vacuum in the bulb was an excellent insulator and no current would flow. He observed that when the plate was connected to the negative side of the hot filament, no current flowed but when the plate was connected to the positive side, a current was indicated.

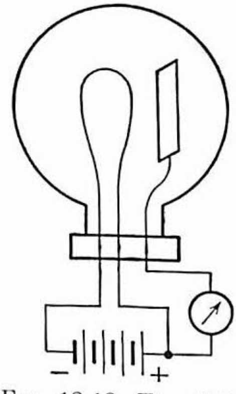
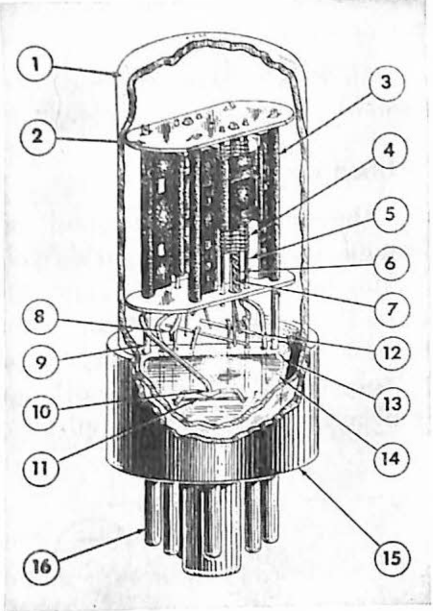


FIG. 18-18. The Edison effect.

This so-called *Edison effect* is the basic phenomenon of the vast field of electronics. The fact that electrons will flow only from the hot filament to the positive plate and not in the reverse direction permits the two-electrode tube, or *diode*, to be used as a *rectifier* to convert alternating currents to unidirectional currents. The fact that the rate of flow is extremely sensitive to the electric fields which can be set up between the filament and the plate led to the development of the *amplifier*. The fact that some of the output of an amplifier can be fed back into the input to provide *regeneration* permits the use of a vacuum tube as an *oscillator*.



Parts and Materials in Typical Electron Tube

(1) Envelope—lime glass. (2) Spacer—mica sprayed with magnesium oxide. (3) Plate—carbonized nickel or nickel-plated steel. (4) Grid wires—manganese-nickel or molybdenum. (5) Grid side rods—chrome copper, nickel, or nickel-plated iron. (6) Cathode—nickel coated with barium-calcium-strontium carbonates. (7) Heater—tungsten or tungsten-molybdenum alloy with insulating coating of alundum. (8) Cathode tab—nickel. (9) Mount support—nickel or nickel-plated iron. (10) Getter support and loop—nickel or nickel-plated iron. (11) Getter—barium-magnesium alloys. (12) Heater connector—nickel or nickel-plated iron. (13) Stem lead-in wires—nickel, dumet, copper. (14) Pressed stem—lead glass. (15) Base—bakelite. (16) Base pins—nickel-plated brass. (*Radio Corporation of America.*)

Electron Emission

In all electron tubes the first requirement is a stream of free electrons. Within a copper conductor, electrons move freely from atom to atom because they are simultaneously attracted to many positive nuclei and there is no net unbalanced force. If an electron is to leave the surface, however, it must have enough energy to overcome the attraction of the positive charge which it leaves behind. The situation is somewhat similar to boiling water, where the water molecule requires extra energy to change to the high-energy vapor state.

To free electrons from a conductor, energy must be added to the electrons. If the added energy is in the form of heat, it is called *thermionic* emission. Light energy can be used in certain cases to produce *photoelectric* emission. Use of the kinetic energy of other rapidly moving electrons causes *secondary* emission. The potential energy of a powerful electrostatic field permits *high-field* emission.

In thermionic emission, which is used in most of the tubes employed in radio and television, the temperature of the conductor is raised until electrons are "boiled out" of the surface. Heat energy is added conveniently by passing an electric current through the emitter, or *cathode*. In high-voltage vacuum tubes the tungsten filament serves as both heater and cathode; for low-voltage applications, the cathode is usually coated with a substance with high emission efficiency and heated indirectly by an electrically insulated filament.

The Vacuum Diode

A diode is a two-electrode tube containing a source of electrons, the cathode, and a receiver of electrons, the plate, or *anode*.

Rectification

In the simple rectifier circuit of Fig. 18-19, the a-c power is supplied through a transformer with two secondary windings. The low-voltage winding heats the filament, and the high-voltage winding applies a voltage across the load and diode in series. When the alternating voltage makes the anode positive with respect to the cathode, a current flows through the tube and the load; when the anode is negative, no current flows. The result is the rectified, but pulsating, direct current shown.

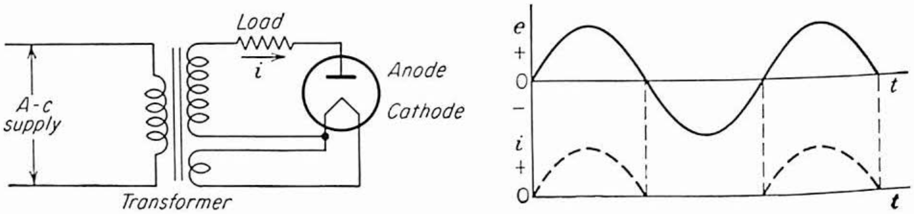


FIG. 18-19. Rectifier circuit and current rectification.

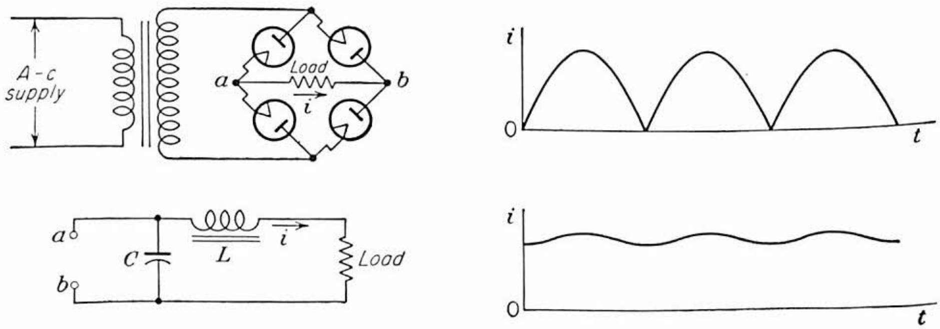


FIG. 18-20. Full-wave rectifier and filter.

Full-wave rectification can be obtained by using the *bridge* rectifier circuit. Note that current always flows from a to b in the load regardless of the polarity of the applied voltage. If a *filter* is connected between the rectifier output terminals ab and the load, the pulsations in current can be greatly reduced and practically eliminated. The condenser tends to absorb current surges, and the inductance coil tends to prevent sudden changes in current in the load.

Detection

The first application of the Edison effect was in the Fleming "valve," which was introduced in 1904 as an improved *detector* of radio waves. The high-frequency radio-telegraph signals are represented in Fig. 18-21*a*. After passing through a half-wave rectifier or detector, the current varies as shown in Fig. 18-21*b*. Filtering out the high-frequency oscillations leaves a low-frequency variation which can be broken up into dots and dashes.

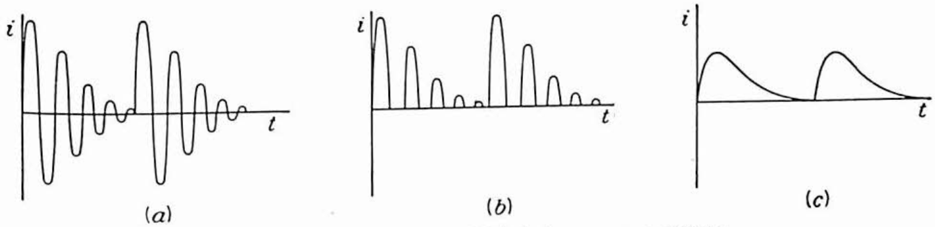


FIG. 18-21. Detection of high-frequency waves.

The Triode

Shortly after Fleming's invention, De Forest patented a three-electrode tube (which he called the "audion") containing a gridlike wire mesh between the cathode and the anode. Changing the voltage on the *grid* produced corresponding changes in the anode current. We now know that the presence of the grid affects the electric field near the cathode and a small negative voltage on the grid will offset a large positive voltage on the plate. Since a small grid-voltage variation can cause a large change in anode current and the changing anode current can produce a large voltage variation across a load resistor, *amplification* is possible.

Amplification

In the simple amplifier circuit of Fig. 18-22, the alternating input signal is added to the steady grid voltage (C battery) to provide a varying grid voltage. The *characteristic curve* of the triode indicates what anode current (i_a) will flow with a given grid voltage (e_g). For a sine-wave signal input, the anode current will vary nearly sinusoidally, producing a corresponding output voltage across the load resistance (R_l). For a load resistor of 10,000 ohms, the amplitude of the output voltage is

$$10{,}000 \text{ ohms} \times 0.001 \text{ amp} = 10 \text{ volts}$$

Since the input voltage amplitude is 0.5 volt, the amplification is

$$\frac{\text{Output}}{\text{Input}} = \frac{10}{0.5} = 20$$

In a circuit such as this, the A supply provides for heating the cathode and the B and C supplies place the tube in the proper operating condition for amplification.

In the amplifier, the total output voltage is the sum of a sine wave and a steady (d-c) voltage. The useful power output is due to the a-c component of voltage across the resistance, and it turns out to be equal to one-half the voltage amplitude times the current amplitude. The "one-half" is due to the fact that the current and voltage are varying sinusoidally and *effective* values must be used (see page 324); therefore,

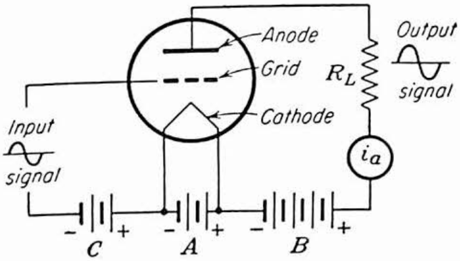


FIG. 18-22. Triode amplifier circuit.

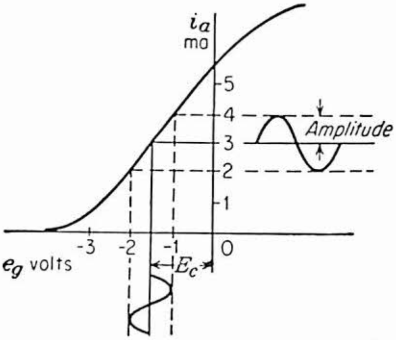


FIG. 18-23. Anode current-grid voltage relation.

$$P = \tfrac{1}{2}EI = \tfrac{1}{2} \times 10 \times 0.001 = 0.005 \text{ watt} = 5 \text{ mw}$$

Since the grid never becomes positive, no grid current flows and the input power is zero. Where does the output power come from? Some of the d-c power from the B battery has been converted to a-c power by the amplifier tube. It is this unique ability of the vacuum tube to control considerable amounts of anode power with no grid power that is the basis for many of the applications of electronics.

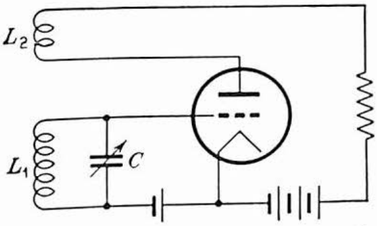


FIG. 18-24. Self-exciting oscillator.

Oscillation

Since the output voltage of an amplifier is greater than the input voltage, part of the output could be fed back into the input to produce even greater output. If conditions are just right, the portion of the output voltage fed back may provide just enough input voltage to produce the output voltage and no other input source is needed; then the tube is a "self-excited oscillator" producing an a-c output with no a-c input.

The frequency of the oscillation is dependent on some part of the circuit which is sensitive to frequency. In Fig. 18-24, it is the combination of inductance L and capacitance C. In other cases it may be a combination of resistance and capacitance. In radio transmitters it is commonly a small quartz plate which vibrates mechanically and which is coupled into the electric circuit. A clock is analogous to an oscillating circuit in that unidirectional (d-c) power is supplied by the spring (battery) to the oscillating pendulum whose frequency is determined by its length and mass (circuit constants).

The Cathode-ray Tube

In addition to diodes and triodes, there are multielectrode tubes to serve a great variety of special purposes. One of the most interesting is the cathode-ray tube, of which the television "picture" tube is a special case. Surprisingly, the modern picture tube is very similar to the discharge tube used by J. J. Thomson in the early experiments which determined the nature of the electron.

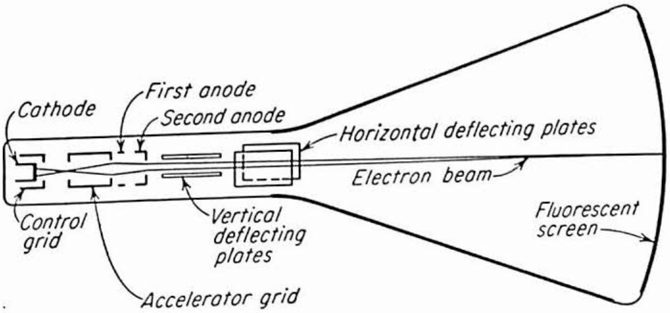
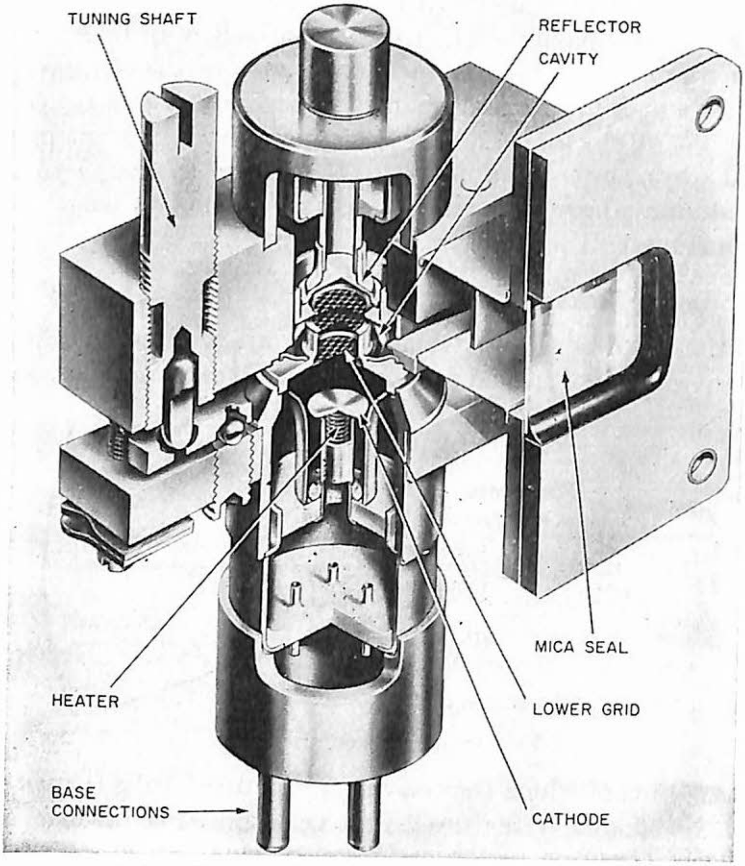


FIG. 18-25. Cathode-ray tube.

The essential elements of a cathode-ray tube (Fig. 18-25) are an *electron gun* consisting of cathode, grid, and anodes to provide a sharply focused beam of fast moving electrons; horizontal and vertical *deflecting plates* to direct the electron beam in accordance with the signal voltages; and a *fluorescent screen* which changes the kinetic energy of the electrons into visible light. In a television set the electron beam crosses and recrosses the screen, leaving a series of lines of varying light intensity which give the appearance of a picture. The associated vacuum-tube circuits are very complex, but basically they are all performing the functions of rectification, amplification, and oscillation.

ELECTRONIC DEVICES

The impact of electronics on our modern world can be indicated by brief descriptions of the performance of some recently developed electronic devices.

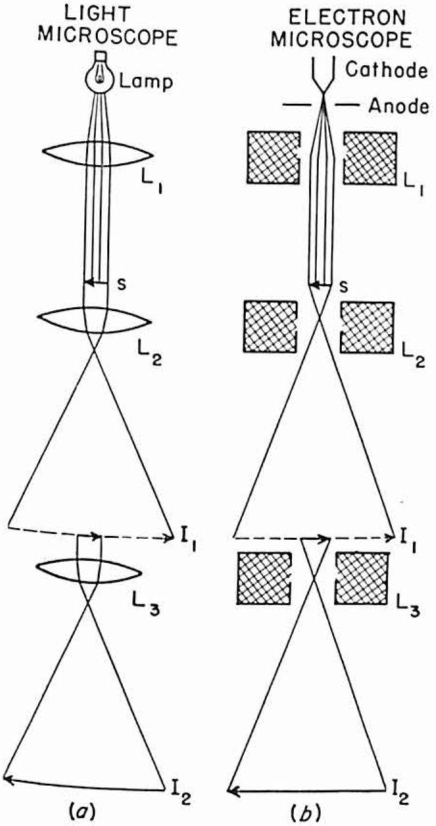


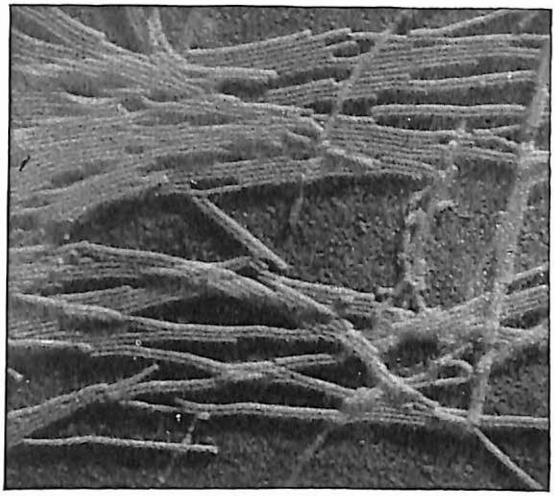
Reflex Klystron Tube for Generating Microwaves

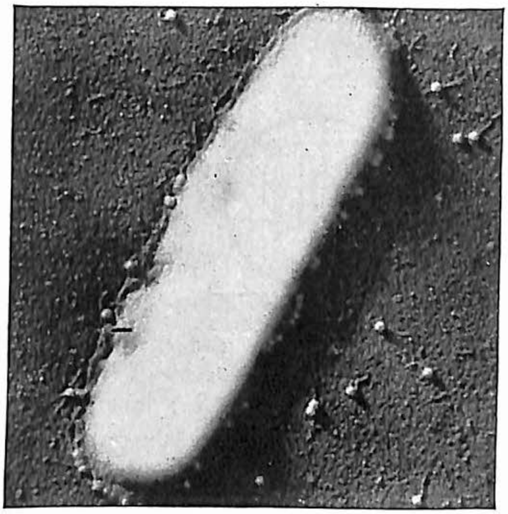
When an electron is accelerated it absorbs electrical energy; when it is slowed down, it gives up that energy. In a properly designed vacuum tube, these energy interchanges can be made to occur 10 billion times a second, thus generating electric waves of very high frequency and very short wavelength which are ideal for radar applications. In the klystron current flows through the *base connections* to the *heater* and heats the *cathode* which gives off electrons. The *lower grid*, positively charged, attracts the electrons. The top pair of grids tends to "bunch" the electrons by slowing down some and speeding up others. The *reflector* reflects the bunched electrons back through the grids where the voltage is such that the electrons are decelerated and their energy is transferred in waves to the radio-frequency field in the surrounding *cavity*. The *mica window* seals the vacuum in the tube but permits the microwave energy to pass through. The frequency of the output can be varied by the *tuning shafts* which change the grid spacing. (*Varian Associates.*)

Radar

Radio detecting and ranging (*radar*) was used extensively in World War II to detect aircraft, ships, and submarines. A powerful high-frequency transmitter sends out a short pulse of just a few microseconds duration. The sharply beamed electromagnetic energy travels out until it strikes a







Electron Microscopy

The similarity between optical and electron microscopes is shown in the drawing (above, left) comparing the beam sources and lenses. Specimen S is placed in front of objective lens L_2; final image I_2 is projected onto a fluorescent screen. The value of the electron microscope in studying invisible objects is illustrated by photos (top right) of elementary bodies of tobacco virus at a magnification of 53,000 times and (bottom right) of a sperm-like bacteriophage attacking a colon bacillus (× 21,000). *(From Ralph W. G. Wyckoff, "Electron Microscopy," Interscience Publishers, Inc., New York, 1949.)*

reflecting object. The reflected energy is picked up on a sensitive receiver, and the distance traveled by the radiated energy at 186,000 mps is indicated by the time delay between the transmitted and reflected pulses. In 1946, using a special radar unit, the United States Signal Corps directed some electromagnetic energy toward the moon. About 2.4 sec later, there appeared on the radar screen an echo pulse indicating that radar contact had been established with the moon. On the basis of this observation, about how far away is the moon?

The Electron Microscope

The magnification obtainable with an optical microscope is limited to about 2,000 times because of the fundamental fact that the reflecting object must be relatively large compared with the wavelength of the incident light. In some ways an electron beam behaves as a wave motion like light but with a very short wavelength. An electron microscope uses an electron gun, a fluorescent screen, and a series of focusing devices which provide the equivalent of glass lenses in an optical microscope. Magnifications of 20,000 times can be obtained directly, and photographic enlargements provide the equivalent of 100,000 times. By means of the electron microscope scientists have looked into the hitherto unknown and studied viruses and bacteria and the structure of complex molecules.

The Phototube

The fact that electrons can be freed from a surface by the absorption of light energy of the proper wavelength is the basis of operation of a group of electronic devices called *phototubes.* These photosensitive devices are used in motion-picture projectors, measurement and counting devices, inspection and control apparatus, and a host of other applications where they substitute for human eyes and fingers or elaborate mechanical equipment.

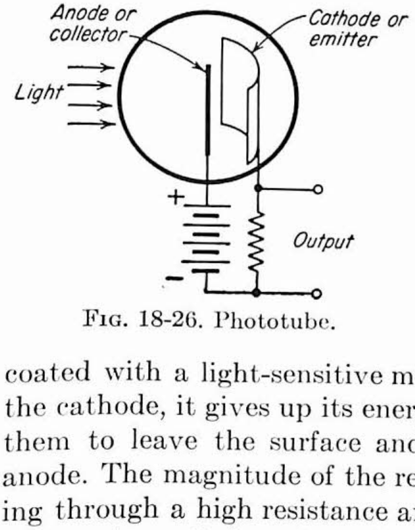


FIG. 18-26. Phototube.

The construction of a simple vacuum phototube is as shown in Fig. 18-26. The cathode is made of silver or nickel coated with a light-sensitive material such as cesium. When light strikes the cathode, it gives up its energy to electrons in the surface and permits them to leave the surface and be attracted to the positively charged anode. The magnitude of the resultant current is very small, but in flowing through a high resistance an appreciable voltage is developed. If this voltage is applied to the grid of a triode tube, it can be amplified so that the resulting current will operate relays and switches.

The use of phototubes to convert the variations of light from a motion-picture sound track into voice currents is well known; less well known are some of the industrial applications such as the photoelectric pinhole detector for tin plate. The tin plate used in making cans for food storage must be free from the tiniest of holes in the protective tin coating. The pinhole detector consists of an intense light source, a group of phototubes, and a control unit. As the tin plate speeds through the shearing line at 1,000 ft per min, the detector scans the sheet and automatically spots and marks holes smaller than $\frac{1}{64}$ in. in diameter.

The Gas-filled Tube

One of the disadvantages of the high-vacuum electron tube is that high voltages and large emitting surfaces are required to provide appreciable currents; this limitation does not exist in the *gas-filled tube*, which is, by comparison, a low-resistance device.

Consider a diode into which a small amount of gas has been introduced. As an electron is accelerated toward the plate, it may strike a gas atom and, if the collision is violent enough, knock off an orbital electron. The two free electrons move toward the plate, and each may again strike an atom of gas and free an additional electron, progressively increasing the anode current. At the same time the gas atoms which have lost electrons are now positive *ions*, and they drift toward the cathode, making the space around the cathode more positive and thereby facilitating the removal of electrons. As a result of these two effects large currents can flow through gas tubes with little voltage drop and therefore low power losses.

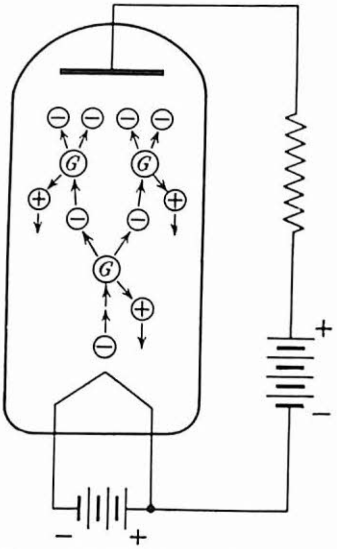


FIG. 18-27. Ionization in a gas-filled tube.

Examples of industrially important gas-filled tubes are the *thyratron* and the *ignitron*. The thyratron is a three-electrode tube filled with a gas such as hydrogen. When the thyratron is used as a rectifier, the point in the a-c cycle at which current begins to flow (or where the tube *fires*) is controlled by the grid. The thyratron becomes an easily controlled and timed "electronic switch" capable of carrying heavy currents. The maximum instantaneous current in a thyratron is limited by electron emission at the cathode; the ignitron uses for its electron source a pool of mercury which will provide an almost unlimited supply of electrons. Water-cooled ignitrons are made in capacities up to 10,000 amp for use in rectifying large currents for welding or for processes where direct current is necessary. Ignitrons are preferred over motor-generator sets because of their higher efficiency, absence of noise, and simplicity of operation. In terms of power-handling capacity, the several million kilowatts of ignitrons installed constitute the greatest industrial application of electronics.

THE FUTURE OF ELECTRODYNAMICS

Because of the efficiency and precision with which electrical energy can be controlled and converted into other forms of energy, electrodynamic devices are employed in a great variety of applications. In addition to the situations in which only electrical energy can be used (as in radio communication and electrometallurgy), phototubes, electron tubes, electronic timers, strain gages, servomechanisms, and telemetering systems have made electrical circuits and devices competitive with optical, mechanical, and hydraulic units and even with human eyes, ears, noses, and fingers. New developments have come so rapidly that the only conclusion possible is that the future of electrodynamics is unlimited.

ASSIGNMENTS

EXERCISES: Assignments 18-1 to 18-13 are idealized problems to illustrate principles.

18-1. A 20-μf condenser is charged with a current of 100 ma. Calculate the voltage after 3 sec. How many electrons have been stored? How much energy is stored in the electric field? (Answer: 15,000 volts, 1.89×10^{18} electrons, 2,250 watt-sec)

18-2. A 10-henry inductance coil carries a current which is changing at the rate of 200 ma in $\frac{1}{50}$ sec. What is the voltage across the coil? When the current is 500 ma, what is the energy stored in the magnetic field?

18-3. What voltage would be required to produce a current of 3.5 amp in a 72-ohm resistance? (Answer: 252 volts)

18-4. An iron operates with 8.33 amp at 120 volts. What is its power rating?

18-5. Approximately how much per month would it cost to operate the iron (Prob. 18-4) 3 hr per week if electricity costs 3 cents per kwhr? (Answer: 36 cents)

18-6. What is the operating resistance of a 2.5-kw, 240-volt heater?

18-7. The four-pole generator in Fig. 18-11 is to be rewound to produce 240 volts at 1,200 rpm. If the new field winding provides 1.2 million lines of flux per pole, how many conductors should be connected in series? (Answer: 250)

18-8. A certain 220-volt d-c motor develops 5 hp at 1,500 rpm with an input current of 22 amp. What power would be developed at 1,200 rpm with a current of 11 amp?

18-9. What is the rated full-load efficiency of a 20-hp, 1,200-rpm, 240-volt, 75-amp d-c motor? What are the losses? In what physical forms do these losses appear? (Answer: 83 per cent, 3.06 kw)

18-10. The flux in the iron core of a 60-cycle transformer varies from 0 to 250,000 lines in one-eighth of a cycle ($\frac{1}{480}$ sec). What average voltage is induced in a 1,000-turn coil wound on the core? (Answer: 1,200 volt)

18-11. A 50-kw distribution transformer has full-load losses of 1,050 watts. What is the rated efficiency?

18-12. In an audio-frequency amplifier tube, an input signal of 20 mv produces a plate-current variation of 0.15 ma. What should be the value of the load resistance to provide a voltage amplification of 15? If two similar amplifier stages are used, what is the over-all amplification? (Answer: 2,000 ohms, 225)

18-13. The resonant frequency of oscillation of a coil-condenser combination is given by the equation $f = 1/2\pi\sqrt{LC}$, where f is in cps, L in henrys, and C in farads. What inductance is needed to tune a 0.003-μf condenser to the Conelrad frequency of 640 kc?

PROBLEMS: Assignments 18-14 to 18-17 are electrical engineering problems to be solved by the complete five-step approach outlined in Chap. 15. Your instructor will discuss with you the simplifying assumptions which can be made. Some useful data are given in Appendix A.

18-14. Your school is planning to set up a special test unit at point *A* near the engineering building. Power is to be supplied from point *B* (points *A* and *B* to be designated by your instructor). A maximum of 15 kw at 220 volts will be required. Specify what will be needed in the way of cable if the line voltage drop is not to exceed 20 volts.

18-15. Late-summer irrigation on a western ranch required 100 hr of continuous pumping at 200 gpm. The water outlet is 110 ft above the water table. The electric bill for the month for pumping and domestic service was $29.60. If electrical energy averages 3 cents per kwh, did the power company make a mistake?

18-16. On a construction job, a pump is needed for 8 hr for every working day for a year. The pump requires 20 hp to drive it. The mechanic on the job suggests using a 20-hp gasoline engine which is available. The electrician suggests that 220-volt power is available if you wish to install an electric motor; he thinks a 20-hp motor would cost about $300 and would have a salvage value of approximately $150. What do you recommend?

18-17. You are the plant engineer of a small manufacturing company. A new boring mill with a 20-hp d-c motor is to be installed. Available at the site is a 230-volt line of No. 4 AWG wire, fused for 90 amp. The electrical code permits 60 amp continuous in standard No. 4 AWG rubber-covered wire in conduit. You note that in the same shop there is a 10-hp d-c motor supplied at 115 volts through 125-amp fuses. Is the available 230-volt line adequate for the new boring mill?

19

PREVIEW OF ENGINEERING ECONOMY

In defining engineering, emphasis was placed on efficiency, and there are innumerable examples of how engineers have worked to improve the efficiency of engines, machines, processes, and circuits. In actual practice, however, an engineer must know when to stop increasing efficiency, because efficiency costs money. As an illustration, it does no good to increase the efficiency of an automobile engine by raising the compression ratio if the higher compression engine requires more expensive gasoline. For the same reason, the best electric-motor design represents an economic compromise between a high efficiency, which reduces the operating cost, and a low weight of copper and steel, which reduces the initial cost.

Most engineering problems are answered ultimately in dollars and cents. Technical decisions must always be tempered by economic conditions. As a result the engineer often finds that after taking into account the technical factors, a process in which he is experienced and skillful, he must then evaluate economic factors with which he is not so familiar. At the present time, income taxes play such a big part in the financial operations of most companies that a decision to build a plant or replace a machine is made only after consultation with a tax expert.

In many situations engineering knowledge and judgment are used to evaluate the technical factors in money terms, and then economic principles are applied to provide sound comparisons so that proper decisions can be made. The principles which govern the economic aspects of engineering decisions are considered under the name of "engineering economy." Only a brief introduction to this important subject is presented here along with a few examples to illustrate how the engineer makes use of the basic principles.

ENGINEERING ECONOMY

Economy problems begin with a desire to improve the success of an existing operation or a desire to find new opportunities for profitable investment.

EXAMPLE A: Our 10-year-old processing plant is less efficient than new models. Should it be maintained, improved, or replaced?

EXAMPLE B: Our present plant is making a good profit. Should we double its size or begin manufacture of a companion product?

Note that in each case, technical and economical factors are involved. What questions would have to be answered by engineering and what by management?

Present Economy

One group of problems involves factors which can be satisfactorily evaluated in terms of *present* costs and gains.

EXAMPLE C: Should our new plant be located close to raw materials or close to the consuming area?

EXAMPLE D: Should we use aluminum conductors for lightness or copper conductors for cheapness?

In Example C, important factors would include the relative costs of transportation of the raw materials and the finished product and the availability of power and labor. What factors would enter into Example D?

Future Economy

Many problems require determining what is economical over a period of time and involve *future* costs and gains.

EXAMPLE E: Is it justifiable to invest \$50,000 now in a machine which will save \$10,000 a year?

EXAMPLE F: How much per mile does it cost to operate an automobile which will be turned in after 3 years?

All engineering problems involve future happenings; even an investigation of a past design failure is for the purpose of improving future designs. But these are usually in terms of the immediate future. In designing a bridge or an airport, on the other hand, careful attention must be given to anticipated population growth and long-range shifts, possible technological developments and sociological changes, as well as the important problem of paying in the future for something which is to be built now.

TIME VALUE OF MONEY

In considering economic action over a period of time, it must be realized that a dollar now is worth more than the prospect of a dollar a year from now.

Interest

Interest is money paid for the use of money; it is similar to rental, as in the rental of a warehouse or a piece of earth-moving equipment. The cost of money (interest) varies with the amount of risk involved and with the size and duration of the loan. For example, long-term government bonds in large denominations may yield only 2 per cent, the so-called "6 per cent auto loans" actually include interest at 12 per cent, and short-term "personal loans on furniture, paid for or not" may carry as high as 30 per cent interest. The cost of money fluctuates from time to time and, to some extent, it may be controlled or modified by actions of the greatest borrower of all, the Federal government. Like any other commodity, money can be "shopped for" in the open market. Frequently municipalities will sell bonds to the "lowest bidder," in other words, to the qualified organization willing to loan money at the lowest rate.

Basis of Interest

A loan is possible when the *lender* and *borrower* mutually agree on the interest to be charged. The lender charges interest because in loaning his money he gives up the opportunity to use it himself. He could spend it for desirable goods and services—buy a new Cadillac or hire a personal valet. Or he could invest it in productive goods or property—equip a machine shop or buy a part interest in a restaurant. Or he could hoard it or hold it for a better opportunity; perhaps he gets a thrill out of counting his money or he is waiting for just the right time to make a profitable purchase.

On the other hand, the borrower is willing to pay interest on borrowed money because it enables him to do things he could not do otherwise. He can purchase goods or services desired now—that same new Cadillac—and pay later. Or he can purchase goods or property—such as raw materials and processing equipment which, when properly managed, will repay the loan plus the interest plus a reasonable profit.

Factors in the Interest Rate

The rate of interest includes compensation for the use of the money ("pure interest"), insurance against the risk of loss, and service charges to cover work involved in handling the loan. A given lending agency might figure that 4 per cent was a fair return on its money. If home loans resulted in serious losses in 1 case in 200, an additional $\frac{1}{2}$ per cent might be included as insurance. The cost of drawing up papers and recording payments might be taken into account by adding another $\frac{1}{2}$ per cent. The total interest rate for home loans would be 5 per cent. Under other circumstances, a loan on a speculative venture such as developing a uranium mine might involve such a high risk that money would be available only at 12 per cent.

Simple and Compound Interest

Interest is the fraction of the money borrowed to be paid for its use for a definite period and is expressed in per cent. Interest rates are on the basis of 1 year unless another period is specified. For example, the interest on \$1,000 at 5 per cent for 3 years is $\$1{,}000 \times 0.05 \times 3 = \$150$. For 6 months, the interest on \$1,000 at 5 per cent is $\$1{,}000 \times 0.05 \times \frac{6}{12} = \$25$.

When interest is *compounded*, the annual interest is added on to the amount owed and subsequently interest is paid on interest as well as on principal.

EXAMPLE G: Calculate the total sum owed on a principal of \$1,000 for 3 years at 5 per cent compounded annually.

$$\begin{aligned}
\text{At end of first year, sum owed} &= 1{,}000(1 + 0.05) = 1{,}050 \\
\text{During second year, principal is} &= 1{,}050 \text{ or } 1{,}000(1 + 0.05) \\
\text{At end of second year, sum owed} &= 1{,}050(1 + 0.05) \\
&= 1{,}000(1 + 0.05)(1 + 0.05) \\
\text{During third year, principal is} &= 1{,}102.50 \text{ or } 1{,}000(1 + 0.05)^2 \\
\text{At end of third year, sum owed} &= 1{,}000(1 + 0.05)^2(1 + 0.05) \\
&= 1{,}000(1 + 0.05)^3 \\
&= \$1{,}157.63
\end{aligned}$$

Reasoning from this specific case, we see that in general,

$$S = P(1 + i)^n$$

where S is the sum owed after n interest periods from the present date on a present amount P with interest rate i. The quantity $(1 + i)^n$ is called the "single-payment compound-amount factor" and is available in interest tables (see Appendix C).

EXAMPLE H: Find the value 10 years from now of \$200 invested at 6 per cent interest compounded annually.

$$S = P(1 + i)^n = 200(1 + 0.06)^{10} = 200 \times 1.791 = \$358.20$$

EXAMPLE I: Find the *present worth* of \$200 to be paid 10 years from now if money is worth 6 per cent.

Here
$$P = \frac{S}{(1 + i)^n} = \frac{200}{1.791} = \$111.68$$

EVALUATIONS ON DIFFERENT TIME BASES

The two examples just given illustrate the important point that because of the time value of money, one dollar *now* is worth more than one dollar sometime in the *future*. This holds true even if no risk is involved, because a dollar now can be used or invested and that option is valuable. The Federal government recognizes this in offering savings bonds which pay \$4 in 10 years for each \$3 invested now.

In general, an engineering economy problem involves costs and gains at present, during each year for the next several years, and at various stated times in the future. In order to make valid comparisons, all quantities must be placed on the same basis.

Present-worth–Single-payment

The present worth of a sum to be paid in the future is given by

$$P = \frac{S}{(1+i)^n} = S \times \frac{1}{(1+i)^n}$$

as was used in the second example. The term $1/(1+i)^n$ is called the "single-payment–present-worth factor" and is sometimes available in tables. If not, the reciprocal of $(1+i)^n$ can be used.

EXAMPLE J: A given machine is expected to have an estimated salvage value of \$200 after a 10-year life. If money is worth 6 per cent, what is the present worth of the salvage value?

$$P = S \times \frac{1}{(1+i)^n} = 200 \times \frac{1}{(1+0.06)^{10}} = 200 \times 0.5584 = \$111.68$$

Straight-line Depreciation plus Average Interest

In order to compare a present investment with an anticipated annual saving, both quantities must be placed on a common basis—both in the present or both per year.

EXAMPLE K: A machine having an estimated service life of 10 years costs \$20,000. With interest at 6 per cent, calculate the annual savings which should be expected to justify the investment.

One approach is to place the investment on an annual basis; in other words, find the annual charge which is equivalent to an immediate investment. An approximate method of doing this is to make a uniform annual payment on the principal and then include an appropriate interest charge. The amount charged off per year is called "depreciation" and will be the same each year if "straight-line" depreciation, the most common method in this country, is used.

In determining what interest charge is appropriate, it is realized that the interest decreases from a maximum the first year to a minimum the last year as the principal decreases. The customary approach is to use the average of the first and last years' interest. In Example K, then,

$$\begin{array}{lr}
\text{Straight-line depreciation} = \$20{,}000/10 \text{ years} & = \$2{,}000 \\
\text{First-year interest} = 20{,}000 \times 0.06 \quad = 1{,}200 & \\
\text{Last-year interest} = (20{,}000/10) \times 0.06 = \quad 120 & \\
\text{Average interest} = (1{,}200 + 120)/2 = 1{,}320/2 = & \underline{660} \\
\text{Annual cost} = & \$2{,}660
\end{array}$$

In general, where R = annual payment,

$$R = \frac{P}{n} + \frac{Pi + (P/n)i}{2} = \frac{P}{n} + P\left(\frac{i + i/n}{2}\right) = P\left(\frac{2 + ni + i}{2n}\right)$$

In order to find the present worth of a series of annual payments, the formula can be written

$$P = R\left(\frac{2n}{2 + ni + i}\right)$$

EXAMPLE L: A proposed plant modification will result in estimated savings of \$6,000 per year. What is the present value of those savings over an 8-year period if money is worth 5 per cent?

$$P = R\left(\frac{2n}{2 + ni + i}\right) = 6{,}000\left(\frac{2 \times 8}{2 + 8 \times 0.05 + 0.05}\right) = 6{,}000 \times \frac{16}{2.45} = \$39{,}180$$

COMPARISONS BETWEEN ALTERNATES

Most engineering economy problems involve proposed investments of money or of such factors as plant or manpower which have money value. In many problems there are certain qualitative factors such as safety, beauty, or public acceptance which cannot be reduced to money terms; these must be carried along through the study and taken into account when the decision is made. The usual problem is to determine which course of action to follow, in other words, to decide which investment is most likely to be recovered with an attractive return. In order to compare alternatives they must be placed on a common basis.

Annual Cost

One approach is to convert all disbursements to an annual basis.

EXAMPLE M: Two machines which are guaranteed to do the same job are being considered. Machine A costs \$16,000, has a 10-year life, and costs \$200 per month to operate. Machine B costs \$12,000, has a 6-year life, and costs \$150 per month to operate. Neglecting salvage value and all other factors and assuming that money is worth 8 per cent, compare these alternatives on an annual basis.

Machine A

Cost of capital recovery =

$$R = P\left(\frac{2 + ni + i}{2n}\right) = 16{,}000\left(\frac{2 + 10 \times 0.08 + 0.08}{2 \times 10}\right) = \$2{,}304$$

Operating cost = \$200/mo × 12 mo = 2,400

Total annual cost = \$4,704

Machine B

Cost of capital recovery =

$$R = P\left(\frac{2 + ni + i}{2n}\right) = 12{,}000\left(\frac{2 + 6 \times 0.08 + 0.08}{2 \times 6}\right) = \$2{,}560$$

Operating cost = \$150/mo × 12 mo = 1,800

Total annual cost = \$4,360

Present Worth

Another approach is to convert all disbursements to a present basis.

EXAMPLE N: Two processes are under consideration. To install process A will cost \$2,000 with a 5-year estimated life and operating costs of \$2,000 per year. Process B will cost \$10,000 with an expected salvage value of \$4,000 after 5 years and operating costs of only \$500 per year. If the processes are equal in all other respects, compare these two alternates, figuring interest at 6 per cent.

Process A

First cost = \$2,000

Present worth of operating cost =

$$P = R\left(\frac{2n}{2 + ni + i}\right) = 2{,}000\left(\frac{2 \times 5}{2 + 5 \times 0.06 + 0.06}\right) = 8{,}475$$

Total present worth = \$10,475

Process B

First cost =	\$10,000	
Present worth of salvage = $P = \dfrac{S}{(1+i)^n} = \dfrac{4{,}000}{(1+0.06)^5} =$	2,989	
Net capital cost =	\$7,011	\$7,011
Present worth of operating cost $= 500 \times \left(\dfrac{2 \times 5}{2 + 5 \times 0.06 + 0.06}\right) =$		2,118
Total present worth =		\$9,129

Rate of Return

Some problems are analyzed best by determining the rate of return that can be expected from a given investment.

EXAMPLE O: An existing manual operation requires four men at \$300 per month. A new installation costing \$54,000 will require only one man. If company policy requires that investments pay off in 6 years, what return will this proposal yield?

Annual savings = R = 3 men × \$300/mo × 12 mo	= \$10,800
Present investment required to gain these savings	= 54,000

Therefore,

$$\frac{2n}{2 + ni + i} = \frac{P}{R} \qquad \text{or} \qquad \frac{2 \times 6}{2 + 6i + i} = \frac{\$54{,}000}{\$10{,}800} = 5 = \frac{12}{2 + 7i}$$

Solving,

$$2 + 7i = 12/5 = 2.4$$

or

$$i = \frac{2.4 - 2}{7} = 0.057 \text{ or } 5.7\%$$

Simple and compound interest, present worth, straight-line depreciation, annual payment, and rate of return are some of the elements of engineering economy studies. The calculation of any of these quantities is just a matter of arithmetic and tabulated values. The difficult part of economy problems, as in all other engineering problems, is the reduction of a complex problem to a series of simple steps; this is the part that requires understanding and judgment which only experience can develop.

PROBLEM SOLUTION IN ENGINEERING ECONOMY

The five-step approach previously discussed can be applied to economy problems as indicated in the following outline.

1. Preliminary analysis. Review present operations and consider various means for eliminating difficulties which restrict profits.

Consider new opportunities for profitable investment.

2. Statement. Define the alternatives to be compared.

Enumerate the quantitative and qualitative factors of each alternative.

State the simplifying assumptions.

State the simplified question.

3. Solution. Convert each quantitative factor to a monetary basis at a specific date.

Put receipts and disbursements on a comparable basis considering interest.

List the qualitative factors which cannot be reduced to a monetary basis.

4. Check. Solve the problem using a different approach.

Use a different time basis or a different basis of comparison.

5. Interpretation. Weigh the results, taking into account the assumptions.

Interpret the results, considering the qualitative factors.

Make the decision.

To illustrate the approach, consider the following illustrative problem: For a new project, the Spartan Gadget Co. needs a 200-hp electric motor. What motor shall be purchased?

1. Preliminary analysis. The motor is to supply a certain power at a given speed and any modern electric motor would be suitable.

The decision shall be based on cost alone.

The important factors are first cost and operating cost.

2. Statement. Study reveals the following:

San Jose Electric Co. can supply for \$3,600 a 200-hp motor with a guaranteed efficiency of 88 per cent.

Acme Corp. offers a 200-hp motor, 85 per cent efficiency, for \$3,000.

Electric energy cost averages 1 cent per kwhr.

Spartan Gadget Co. runs one shift, operating 250 days per year.

Company policy requires investments to pay off in 5 years, and interest is figured at 10 per cent.

Electric motors of this type usually last 10 to 20 years.

Assumptions: Assume that motors operate at full-load, 8 hr per day at guaranteed efficiency and that maintenance costs and salvage values are the same for both motors.

Statement: Will the extra \$600 for the more efficient motor pay off in 5 years at 10 per cent under the above assumptions?

3. Solution.

$$\begin{aligned}\text{Output energy} &= 200 \text{ hp} \times 8 \text{ hr/day} \times 250 \text{ days/yr} \times 0.746 \text{ kw/hp}\\ &= 298{,}500 \text{ kwhr/yr}\\ \text{Operating cost} &= \text{input energy in kwhr} \times \text{cost/kwhr}\\ &= (\text{output energy/efficiency}) \times \text{cost/kwhr}\end{aligned}$$

$$\text{San Jose Electric: Cost} = \frac{298{,}500}{0.88} \times 0.01 = \$3{,}390$$

$$\text{Acme Corp.:} \qquad \text{Cost} = \frac{298{,}500}{0.85} \times 0.01 = \underline{3{,}512}$$

$$\text{Saving per year} \qquad = \$\ \ 122$$

The present worth of this saving is

$$P = R\left(\frac{2n}{2 + ni + i}\right) = 122\left(\frac{2 \times 5}{2 + 5 \times 0.10 + 0.10}\right) = 122 \times \frac{10}{2.6} = \$469$$

To gain a saving having a present worth of \$469 requires an investment of \$600.

4. Check. Calculate the return on the \$600 represented by the \$122 saving for 5 years.

Here $P = \$600$, $R = \$122$, and $n = 5$ years; therefore,

$$2 + ni + i = 2n \times \frac{R}{P}$$

or

$$2 + 5i + i = 10 \times {}^{122}\!/_{600} = 2.033$$

or

$$i = \frac{2.033 - 2}{6} = 0.0055 \text{ or } 0.55\%$$

5. Interpretation. Reviewing the assumptions, it is seen that if the motor operates less than the maximum time or at less than full load, the advantage in favor of the less expensive machine will be still greater. The result would be unchanged by assuming a slightly lower interest rate since the return is less than 1 per cent.

The payoff period of 5 years is a critical factor but is not unreasonably short for a speculative venture.

Since the difference is decisive and the assumptions are reasonable, *I recommend that the less efficient motor be purchased from the Acme Corp.*

CONCLUSION

Practically all engineering problems are answered finally in economic terms. As Wellington said, "doing . . . well with one dollar . . . " is a distinguishing characteristic of the engineer. It is not enough that he can make decisions involving technical factors; he must be able to handle the economic factors as well. In addition to having a background of basic economics, he should be familiar with the approaches and techniques used in engineering economy studies. He must recognize the time value of money, be able to make evaluations on different time bases, and be able to make economic comparisons between alternates. Without these abilities, his future will be limited to purely technical activities.

ASSIGNMENTS

EXERCISES: Assignments 19-1 to 19-13 are idealized problems to illustrate principles.

19-1. Calculate the interest on $850 at 6 per cent for 1 year; repeat for 8 months.

19-2. Calculate the total sum owed on a principal of $20,000 for 5 years at 4 per cent compounded annually. Repeat the calculation for semiannual compounding.
(Answer: $24,340; $24,380)

19-3. Find the present worth of $1,500 to be paid in 20 years if money is worth 8 per cent.

19-4. Find the present worth of $5,000 to be paid in 12 years if money is worth 10 per cent. (Answer: $1,593)

19-5. Approximately what is the interest rate paid on a $100 10-year savings bond which costs $75?

19-6. What annual benefit must be expected to justify the installation of a new machine which costs $16,000 and has an estimated service life of 8 years if money is worth 8%? (Answer: $2,720)

19-7. If interest is to be figured at 6 per cent, what should be the minimum service life of a tool which costs $1,200 and saves $450 per year?

19-8. What is the rate of return on an investment of $8,000 which yields a benefit of $2,000 per year for 5 years? (Answer: 8⅓%)

19-9. How much can be spent profitably for a modification of an assembly line which will save $4,000 per year over a 6-year period if money is worth 7 per cent?

19-10. A man buys a $13,000 house with a down payment of $1,000. If the balance is to be paid over a 20-year period with interest at 5 per cent, approximately what are his monthly payments? What is the total amount paid for the home?
(Answer: $76.25; $19,300)

19-11. A wooden bridge across a small creek will cost $12,000 and require $500 worth of annual maintenance during its estimated 10-year life. A concrete bridge will cost $35,000 and require practically no maintenance during its 30-year life. Assuming that money is worth 4 per cent, compare these two alternatives on an annual basis. Repeat for 6%. (Answer: Wooden $1,964 per year; concrete $1,890 per year)

19-12. It has been planned to install a 6-in. pipeline at a cost of $4,000 for a certain service. It appears that a 9-in. pipeline costing $6,000 will result in annual savings of $400 in pumping costs. The expected service life of both installations is 6 years. Calculate the rate of return on the additional investment.

19-13. An investor is considering the purchase of an office building. The average net income is estimated to be $5,000 for 10 years. He estimates that the property can be sold for $30,000 at the end of 10 years. What price can the investor afford to pay if he expects to realize 8% on his investment. (Answer: $48,620)

PROBLEMS: Assignments 19-14 to 19-17 are engineering economy problems to be solved by the complete five-step approach outlined in Chap. 15. Your instructor will discuss with you the simplifying assumptions which can be made. Some useful data are given in Appendix A.

19-14. Your company has an old pump driven by an electric motor. The over-all efficiency of the unit is 50 per cent, and the annual power bill is $1,400. A replacement unit having an over-all efficiency of 70 per cent is available for $2,000. The old unit has a salvage value of $200. If money is worth 6 per cent and investments of this type should pay off in 5 years, what do you recommend?

19-15. For an outlying project a source of power is required by the Atlas Mining Corp. Two alternatives are being considered. An appropriate diesel engine will cost

$5,500 including installation. Maintenance will run approximately $300 per year, and fuel oil will cost $2,000 per year.

An electric motor of the same rating will cost only $3,000, but the necessary power-line installation will cost $7,500. Electrical maintenance will run $50 per year on the motor and $100 per year on the power line. Annual electrical-energy cost is estimated at $1,050.

It is expected that this project will be operating for about 10 years, at the end of which time the site will probably be abandoned. Which power source do you recommend?

19-16. Your company needs some additional warehouse space. A local real estate man agrees to lease you a suitable warehouse and pay all maintenance costs for $400 per month. You can purchase a building site for $4,500 and construct a building for $40,000. After a few years a building of this type drops in value to about one-half its replacement cost. Annual maintenance, taxes, and insurance will cost $800 per year if you own your own building. Which do you recommend?

19-17. The Monterey Fish Company is installing a 5-ton refrigeration unit. Engineers have calculated that for 24-hr operation the monthly water bill would be approximately $95 during the 5-month fishing season.

It has been suggested that an evaporative condenser be purchased instead so that cooling water may be recirculated. A suitable condenser will cost approximately $1,200 more than the condenser originally contemplated. What do you recommend?

20

WHO SHOULD STUDY ENGINEERING

As indicated in Chap. 1, the primary objective of this book is to provide the information about engineering needed by a young person contemplating a career in this field. If the author has accomplished his purpose, you should know what engineering is, what engineers do, and how they go about doing it. You should also have learned something about your own interests and abilities from your reaction to the reading material and the assignments. The third step in career selection is a comparison of your desires with what engineering has to offer and a check of your qualifications with those required for success in engineering.

CONCLUSIONS ABOUT ENGINEERING AS A CAREER

To help you in your analysis, let us first list some broad conclusions which can be drawn from previous discussions and then raise some questions which you alone can answer.

Engineering Is Important Work in This Technological Age

The results of engineering affect everyone on the earth. The engineer contributes to the health, standard of living, and general welfare of all. He is depended on to provide adequate defenses for our country; at the same time, by developing new sources of power, increased supplies of food, and more rapid transportation and communication, he is removing some of the causes of want and fear which lead to conflict between nations.

The engineer is a vital link between the scientist in his laboratory and the general public. His raw material consists of new discoveries, new ideas, new knowledge; it is his job to convert scientific advances to practical forms, produce them economically, and operate them efficiently. As a result of the engineer's work, every industrial worker, farmer, and housewife has command over many mechanical slaves which have, to a large extent, freed human beings from drudgery and toil.

Engineering Includes a Wide Spectrum of Functions

Of particular interest to prospective students is the fact that engineering is not a single activity; instead it embraces a wide variety of functions with rather distinctive features. In order of decreasing emphasis on scientific technology, the major functions are research, development, design, construction, production, operation and maintenance, application and sales, industrial, and management.

For work in research, development, and design, the engineer must have intensive training in science and mathematics. Graduate work is highly desirable. Imagination and creativity in scientific aspects and skill in experimentation are important qualifications. On the other hand, knowledge of engineering practice and skill in handling economic factors are not so important.

In the functions of construction, production, operation, and maintenance, the major emphasis is on the art of engineering—solving technological problems economically, efficiently, and on schedule. For work in these functions a feeling for what machines and men can do is important. There is need for skill in human relations and in solving personal problems of a type which may not enter into a research engineer's work.

Management, industrial, and sales functions are similar in that human and economic factors are frequently more important than technological factors. The engineer's personal characteristics may be more important than his scientific training. Problems tend to be more qualitative in nature than in other functions, and precise mathematical methods are not applicable. Sensitivity in human relations and understanding of basic human drives are necessary for success.

Engineering Is a Broad Field with Branches to Meet Any Technical Interest

Engineering is an attitude or an approach rather than a specific subject. At one extreme the engineer is concerned with colossal structures and tremendous energies; at the other end of the size scale he is solving the mysteries of molecular structure and the behavior of electrons. Some of his activities are in the realm of theoretical science, and others depend entirely on practical experience. Some of the engineer's problems are purely technical and quantitative; others require for their solution a fine sense of human relations.

The engineer works with foods and fertilizer; penicillin and perfume; jet planes and baby carriages; ore crushers and dishwashers; radio waves, sound waves, and tidal waves; steam turbines and steam irons; solar furnaces and home refrigerators; steel cable and nylon thread. Within the broad branches of civil, mechanical, electrical, mineral, or chemical engineering or within the more specialized subfields, any technically minded person can find an area of interest.

Engineering Is Difficult Work Requiring Special Abilities

The distinguishing characteristic of an engineer's work is the emphasis on quantitative thinking—reasoning in mathematical terms and performing calculations with numbers and symbols. He makes use of advanced mathematical methods and abstract concepts which, for many people, are extremely difficult to comprehend, let alone apply. In addition, the engineer must be able to express his ideas verbally and graphically.

The engineer's approach to problem solution is based on rational thinking rather than emotional appeal. Logical, step-by-step analysis accompanied by careful checking and leading to well-founded conclusions must become habitual.

The engineer is a doer as well as a planner, and frequently he is responsible for the completion of an over-all project involving many other people. He must be able to work long hours and under pressure in situations where every hour of delay means financial loss.

The rapid rate of technological progress makes engineering education a lifetime project. After 4 or 5 years of intensive study, the new graduate finds that he has a knowledge of fundamentals but knows little of the art of engineering. He must study at work and in his spare time to learn his particular job. To keep up with new developments he must study the technical journals and attend meetings and conferences. If he ever stops learning, he is quickly left behind and is of little use to his employer or his client.

The Engineer Is One Member of the Technical Team Which Includes the Technician and the Scientist

The technician usually specializes in one aspect of engineering, and therefore his training can be less extensive and more intensive and he becomes productive with less experience. Working with engineers, he uses mathematics and science in solving problems, he uses precision instruments for making measurements, and he may use tools for construction. A technician usually has a strong interest in the practical aspects of technology and less interest in scientific theory. He should have skill in manipulating apparatus and equipment along with the ability to handle elementary mathematics and science.

The scientist is also a specialist but at an advanced level usually requiring graduate work. He is engaged in discovering new principles and learning new facts without being concerned with practical applications. He sometimes works with engineers, contributing his specialized knowledge to the solution of their problems. The scientist needs a high level of intelligence, ability in creative thinking, and skill in experimentation.

Training for Engineering Is Expensive in Terms of Time, Money, and Effort

The generally accepted qualifications for engineering work include the bachelor's degree, which requires a minimum of 4 years' intensive work and study. Deciding to attend college means investing valuable time in hopes of a later return. The loss of opportunity to earn represents an investment of thousands of dollars on the part of the student. The cost of providing qualified teachers, up-to-date laboratories, adequate libraries, and other necessary facilities will amount to several thousand dollars more. The mastery of technical subjects is highly satisfying to successful students, but engineering study is difficult and exacting and requires long hours of concentrated application.

Engineering Work Is Satisfying and Rewarding

The engineer is engaged in creative, productive, and constructive work. Whereas the doctor's patients are usually ill and the lawyer's clients are in trouble, the engineer is primarily concerned with healthy, growing, and productive activities. He has his problems with sick processes and production bottlenecks, of course, but for the most part his work is positive—involving advances, improvements, and benefits. Every successful engineer knows the joy of creation—creation of a new concept, device, process, or procedure out of his own knowledge, thought, and experience.

There is an expanding demand for creative engineers. Every foreseeable technological development will increase the need; automation, operations research, nuclear energy, space travel, weather control, materials design, advances in transportation and communication, all will require more technically trained persons and fewer laborers. Starting salaries for engineering graduates are relatively high, and for qualified engineers there are many opportunities for increased responsibility and compensation. While public acclaim comes to few members of the engineering profession, one's colleagues are quick to recognize professional competence and to honor outstanding achievement.

YOUR QUALIFICATIONS FOR ENGINEERING

Success in engineering requires a combination of interest, aptitude, and drive.

Are You Interested in Engineering?

Over a period of 10 years the author has been questioning groups of graduating seniors regarding what they are seeking in their employment;

almost invariably, at the top of the list they put "interesting work." Interesting work arouses your curiosity and commands your attention. Where do your interests lie?

Look back over your life and see what ideas, things, and activities commanded your attention or aroused your curiosity. Have you always been interested in mechanical or electrical devices? What do you do in your spare time when you can do just what you like? Do your hobbies indicate an interest in technical things or abstract ideas? Are you fascinated by descriptions of new technical or scientific developments? Do you like mathematical puzzles? Would you like to work in a field where a considerable portion of your time would be spent in solving mathematical problems?

Which parts of the text did you find most interesting? Have you ever on your own initiative visited a plant or refinery or radio station or construction project? Have you ever sought out an engineer and questioned him about his work? Do you have sufficient interest in engineering to select it as a lifetime profession?

Are Your Aptitudes in Line with the Requirements for Engineering?

On the basis of many observations as well as carefully devised tests, engineering educators agree that ability in mathematics is most closely associated with success in engineering study. How good are you at reasoning in quantitative terms? Can you manipulate abstract symbols without confusion? How easily did you follow the discussion of the binary number system? Would you rather read *about* carburetors or perform calculations on their performance? Do you grasp mathematical relations quickly, or do you need lots of time for mastery? How did your high school teachers rate your ability in mathematics?

Next to mathematics, perhaps physics is the best indicator of your probable success in engineering study. Are you able to read the statement of a physical principle such as Newton's law of gravitation, understand the relationship among the variables, and visualize how the principle is applied in practice? Do abstract concepts such as acceleration, absolute zero temperature, and magnetic flux seem clear and easy to understand? How well did you understand the discussions of work and energy, voltage generation, coefficient of performance? Were you able to solve the problems involving applications of these ideas?

There are other aptitudes which will contribute to success in engineering, but they are probably secondary in importance; they are modifying factors rather than primary determining factors. Are you able to translate ideas expressed in words into clear sketches? Are you able to describe in words a complex motion such as the action of the valves in an automobile engine? How well do you get along with people? Can you persuade others to your way of thinking? Can you get a group of people to work together efficiently? Can you provide leadership which others are willing to follow?

Do You Have the Drive Necessary for Engineering Study and Practice?

Engineering study is not only difficult, but it is also exacting. There is so much to learn and so little time that many hours of concentrated and efficient study are required. Because so much of engineering is quantitative, a high degree of accuracy is necessary in measurements, observations, and calculations. "Almost right" or "correct except for the decimal point" is not acceptable.

How are you at getting things done? Are you in the habit of carrying assigned projects all the way through to completion? On time? Are you a self-starter, setting your own tasks and completing them? On difficult assignments in the technical portion of this book were you willing to work a little bit harder? When you have made up your mind to do something, do obstacles serve as a challenge bringing out your best efforts? Do you have the drive required to complete an engineering curriculum and gain the necessary preprofessional experience?

Success in engineering usually requires interest, aptitude, and drive; however, a deficiency in one characteristic can be compensated for by extra strength in the other two. There are numerous examples of competent engineers who were low on aptitude but made up for it in interest and drive. Occasionally a student with high aptitude does not have a strongly developed interest. He may get along well in engineering and develop an interest after getting on the job, or more likely, he would do even better if he could but determine where his interests lie.

For the qualified person with technical interests, engineering is a wonderful field full of a host of opportunities for exciting, satisfying work and a lifetime career. Good luck !

APPENDIX A

ENGINEERING DATA

Work = force × distance moved in the direction of the force.

Power = rate of doing work or work per unit time.

1 hp = 746 watts = 33,000 ft-lb per min = 2545 Btu per hr.

The Btu is a unit of heat energy (page 282); 1 Btu = 778 ft-lb.

Diesel oil has a heating value (page 293) of around 160,000 Btu per gal.

Gasoline has a heating value of around 120,000 Btu per gal.

Water weighs approximately 62.4 lb per cu ft.

The efficiency of electric motors (page 319) in the range of 5 to 25 hp is around 80 per cent.

The efficiency of diesel or gasoline engines (page 297) from 5 to 25 hp is around 20 per cent.

The efficiency of centrifugal pumps in the range of 200 to 1,000 gpm is around 65 to 75 per cent.

In some parts of the country, electrical energy costs 3 cents per kwhr on a domestic rate, 2 cents per kwhr on a commercial-industrial rate, and 1 cent per kwhr on a heavy industrial rate.

Typical interest rates are as follows: public works, 3 per cent; homes, 5 per cent industrial buildings, 6 to 7 per cent; industrial equipment 8 to 10 per cent; speculative ventures 12 to 15 per cent.

APPENDIX B

TRIGONOMETRIC FUNCTIONS

Deg	sin	cos	tan	Deg	sin	cos	tan
0	0.0000	1.0000	0.0000	45	0.7071	0.7071	1.000
1	0.0175	0.9998	0.0175	46	0.7193	0.6947	1.036
2	0.0349	0.9994	0.0349	47	0.7314	0.6820	1.072
3	0.0523	0.9986	0.0524	48	0.7431	0.6691	1.111
4	0.0698	0.9976	0.0699	49	0.7547	0.6561	1.150
5	0.0872	0.9962	0.0875	50	0.7660	0.6428	1.192
6	0.1045	0.9945	0.1051	51	0.7771	0.6293	1.235
7	0.1219	0.9925	0.1228	52	0.7880	0.6157	1.280
8	0.1392	0.9903	0.1405	53	0.7986	0.6018	1.327
9	0.1564	0.9877	0.1584	54	0.8090	0.5878	1.376
10	0.1736	0.9848	0.1763	55	0.8192	0.5736	1.428
11	0.1908	0.9816	0.1944	56	0.8290	0.5592	1.483
12	0.2079	0.9781	0.2126	57	0.8387	0.5446	1.540
13	0.2250	0.9744	0.2309	58	0.8480	0.5299	1.600
14	0.2419	0.9703	0.2493	59	0.8572	0.5150	1.664
15	0.2588	0.9659	0.2679	60	0.8660	0.5000	1.732
16	0.2756	0.9613	0.2867	61	0.8746	0.4848	1.804
17	0.2924	0.9563	0.3057	62	0.8829	0.4695	1.881
18	0.3090	0.9511	0.3249	63	0.8910	0.4540	1.963
19	0.3256	0.9455	0.3443	64	0.8988	0.4384	2.050
20	0.3420	0.9397	0.3640	65	0.9063	0.4226	2.145
21	0.3584	0.9336	0.3839	66	0.9135	0.4067	2.246
22	0.3746	0.9272	0.4040	67	0.9205	0.3907	2.356
23	0.3907	0.9205	0.4245	68	0.9272	0.3746	2.475
24	0.4067	0.9135	0.4452	69	0.9336	0.3584	2.605
25	0.4226	0.9063	0.4663	70	0.9397	0.3420	2.747
26	0.4384	0.8988	0.4877	71	0.9455	0.3256	2.904
27	0.4540	0.8910	0.5095	72	0.9511	0.3090	3.078
28	0.4695	0.8829	0.5317	73	0.9563	0.2924	3.271
29	0.4848	0.8746	0.5543	74	0.9613	0.2756	3.487
30	0.5000	0.8660	0.5774	75	0.9659	0.2588	3.732
31	0.5150	0.8572	0.6009	76	0.9703	0.2419	4.011
32	0.5299	0.8480	0.6249	77	0.9744	0.2250	4.331
33	0.5446	0.8387	0.6494	78	0.9781	0.2079	4.705
34	0.5592	0.8290	0.6745	79	0.9816	0.1908	5.145
35	0.5736	0.8192	0.7002	80	0.9848	0.1736	5.671
36	0.5878	0.8090	0.7265	81	0.9877	0.1564	6.314
37	0.6018	0.7986	0.7536	82	0.9903	0.1392	7.115
38	0.6157	0.7880	0.7813	83	0.9925	0.1219	8.144
39	0.6293	0.7771	0.8098	84	0.9945	0.1045	9.514
40	0.6428	0.7660	0.8391	85	0.9962	0.0872	11.43
41	0.6561	0.7547	0.8693	86	0.9976	0.0698	14.30
42	0.6691	0.7431	0.9004	87	0.9986	0.0523	19.08
43	0.6820	0.7314	0.9325	88	0.9994	0.0349	28.64
44	0.6947	0.7193	0.9657	89	0.9998	0.0175	57.29
45	0.7071	0.7071	1.0000	90	1.0000	0.0000	∞

APPENDIX C*

Compound Interest Factors, $C_F = (1 + i)^n$

n	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	n
1	1.010	1.020	1.030	1.040	1.050	1.060	1.070	1.080	1.090	1.100	1
2	1.020	1.040	1.061	1.082	1.103	1.124	1.145	1.166	1.188	1.210	2
3	1.030	1.061	1.093	1.125	1.158	1.191	1.225	1.260	1.295	1.331	3
4	1.041	1.082	1.126	1.170	1.216	1.262	1.311	1.360	1.412	1.464	4
5	1.051	1.104	1.159	1.217	1.276	1.338	1.403	1.469	1.539	1.611	5
6	1.062	1.126	1.194	1.265	1.340	1.419	1.501	1.587	1.677	1.772	6
7	1.072	1.149	1.230	1.316	1.407	1.504	1.606	1.714	1.828	1.949	7
8	1.083	1.172	1.267	1.369	1.477	1.594	1.718	1.851	1.992	2.144	8
9	1.094	1.195	1.305	1.423	1.551	1.689	1.838	1.999	2.172	2.358	9
10	1.105	1.219	1.344	1.480	1.629	1.791	1.967	2.159	2.367	2.594	10
11	1.116	1.243	1.384	1.539	1.710	1.898	2.105	2.332	2.580	2.853	11
12	1.127	1.268	1.426	1.601	1.796	2.012	2.252	2.518	2.813	3.138	12
13	1.138	1.294	1.469	1.665	1.886	2.133	2.410	2.720	3.066	3.452	13
14	1.149	1.319	1.513	1.732	1.980	2.261	2.579	2.937	3.342	3.797	14
15	1.161	1.346	1.558	1.801	2.079	2.397	2.759	3.172	3.642	4.177	15
16	1.173	1.373	1.605	1.873	2.183	2.540	2.952	3.426	3.970	4.595	16
17	1.184	1.400	1.653	1.948	2.292	2.693	3.159	3.700	4.328	5.054	17
18	1.196	1.428	1.702	2.026	2.407	2.854	3.380	3.996	4.717	5.560	18
19	1.208	1.457	1.754	2.107	2.527	3.026	3.617	4.316	5.142	6.116	19
20	1.220	1.486	1.806	2.191	2.653	3.207	3.870	4.661	5.604	6.727	20
25	1.282	1.641	2.094	2.666	3.386	4.292	5.427	6.848	8.623	10.835	25
30	1.348	1.811	2.427	3.243	4.322	5.743	7.612	10.063	13.268	17.449	30
40	1.489	2.208	3.262	4.801	7.040	10.286	14.974	21.725	31.409	45.259	40
50	1.645	2.692	4.384	7.107	11.467	18.420	29.457	46.902	74.358	......	50
100	2.705	7.245	19.219	50.505	......	......	......	......	......	......	100

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COMPOUND INTEREST FACTORS, $C_F = (1 + i)^n$ (*Continued*)

n	12%	14%	16%	18%	20%	25%	30%	35%	40%	50%	n
1	1.120	1.140	1.160	1.180	1.200	1.250	1.300	1.350	1.400	1.500	1
2	1.254	1.300	1.346	1.392	1.440	1.562	1.690	1.822	1.960	2.225	2
3	1.405	1.482	1.561	1.643	1.728	1.953	2.197	2.460	2.744	3.338	3
4	1.574	1.689	1.811	1.939	2.074	2.441	2.856	3.321	3.842	5.007	4
5	1.762	1.925	2.101	2.288	2.488	3.052	3.713	4.483	5.379	7.510	5
6	1.974	2.195	2.437	2.700	2.986	3.815	4.827	6.052	7.531	11.265	6
7	2.211	2.502	2.827	3.186	3.583	4.768	6.275	8.170	10.543	16.898	7
8	2.476	2.852	3.279	3.759	4.300	5.960	8.158	11.030	14.760	25.347	8
9	2.773	3.251	3.804	4.436	5.160	7.451	10.605	14.891	20.664	38.020	9
10	3.106	3.706	4.413	5.234	6.192	9.313	13.786	20.102	28.930	57.030	10
11	3.479	4.225	5.119	6.176	7.430	11.642	17.922	27.138	40.502	85.555	11
12	3.896	4.817	5.938	7.288	8.916	14.552	23.299	36.636	56.703	......	12
13	4.363	5.491	6.888	8.600	10.699	18.190	30.288	49.459	79.384	......	13
14	4.887	6.260	7.990	10.148	12.839	22.737	39.374	66.770	......	......	14
15	5.474	7.136	9.268	11.975	15.407	28.422	51.186	90.140	......	......	15
16	6.130	8.135	10.750	14.131	18.488	35.527	66.542	......	......	......	16
17	6.866	9.274	12.470	16.675	22.186	44.409	86.505	......	......	......	17
18	7.690	10.572	14.465	19.677	26.623	55.511	......	......	......	......	18
19	8.613	12.052	16.779	23.219	31.948	69.389	......	......	......	......	19
20	9.646	13.739	19.464	27.398	38.338	86.736	......	......	......	......	20
25	17.000	26.448	40.900	62.677	95.396	......	......	......	......	......	25
30	29.960	50.922	85.896	......	......	......	......	......	......	......	30
40	93.051	......	......	......	......	......	......	......	......	......	40
50	......	......	......	......	......	......	......	......	......	......	50
100	......	......	......	......	......	......	......	......	......	......	100

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